THE STATE *of* CANADA'S ENVIRONMENT

1996

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1996

Government of Canada

Ottawa
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This book has been produced with both the environment and the reader in mind. The design optimizes the amount of text and graphics and minimizes unused space, while incorporating sufficient white space to be visually attractive. The Times type face and three-column format allow for easy-to-read text and flexibility in illustrations. According to the definitions in the Environmental Choice Program, the text and endleave papers and the binders board used in this publication all contain a minimum of 50% post-consumer and post-commercial recycled fibres, of which at least 10% is of the post-consumer variety. The printing has been done with vegetable oil-based inks.

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Minister's Message

I am pleased to present *The State of Canada's Environment — 1996*, an indispensable reference and learning tool for those wanting a better understanding of Canada's environment, our progress towards sustainability, our successes, and remaining challenges.

Building on the success of both the 1986 and 1991 editions, Canada proudly displays its expertise and leadership in the field of state of the environment reporting with the release of this comprehensive report.

For the first time, our sea-to-sea-to-sea report is simultaneously available to the boardroom, living room, and classroom through Environment Canada's State of the Environment Infobase at the Internet web site — The Green Lane. The sophisticated search functions, fully indexed glossary, and quick, easy downloading of this Internet version make it a modern reference tool. *The State of Canada's Environment — 1996* is also available on CD-ROM, and now, with the inclusion of this print edition in our family of products, there is a format to meet every need.

I am delighted that so many talented and dedicated Canadians worked on the third national report. A remarkable cast of experts from government, the private sector, universities, and nongovernmental groups took part. The broad scope of involvement and participation shows the importance our society places on good environmental information and on making sustainability a reality.

I hope that *The State of Canada's Environment — 1996* will catalyze even more Canadians to put the environment where it belongs: into their thinking and into their actions. I hope that it will help all of us find ways to meet our economic, social, and environmental needs. It shows us what kind of environment we have and must have. Now, it is up to each of us to show our children what kind of environmental citizens we must be.

Sergio Marchi

The Honourable Sergio Marchi
Minister of the Environment

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PREFACE

The State of Canada's Environment — 1996 is Canada's third national state of the environment (SOE) report. As such, it continues the ongoing evolution in national environmental reporting that began several decades ago.

Canada's first national report, released in 1986, was primarily the work of two scientists, Dr. Peter M. Bird, Environment Canada, and Dr. David Rapport, Statistics Canada. This pioneering document, originally intended mainly for a scientific audience, used a forward-looking ecosystem approach, including a stress–response framework, to organize and present information on the state of the environment. At the time of its release, there was no established system for continuous environmental reporting in Canada.

This changed significantly in December 1986, when the federal government authorized Environment Canada and Statistics Canada to establish an ongoing SOE reporting program, with support from other federal agencies. This directive was followed by passage of the *Canadian Environmental Protection Act* in 1988, which made it a legislated requirement for the Government of Canada to "provide information to the people of Canada on the state of the Canadian environment."

This fundamental strengthening and refocusing of environmental reporting to meet the needs of all Canadians was evident in *The State of Canada's Environment — 1991*. This edition of the report was, from the beginning, written and designed specifically for a nonscientific audience of interested Canadians. The ecosystem approach and stress–response framework of the 1986 report were translated into a less technical presentation, built on providing answers to four basic questions:

- What is happening in Canada's environment? (environmental conditions and trends)
- Why is it happening? (link to human activities)
- Why is it significant? (environmental, social, and economic consequences)
- What are Canadians doing about it? (management responses to environmental change)

Attempts at answers were presented in a report that emphasized interpretation rather than presentation of raw data. The ratio of text to graphics was modified from the 1986 report, and elements such as an index and a glossary enhanced the material for a nontechnical audience.

Just as it was important to change the product itself, it was equally important to change the process used to prepare the report. One fundamental change, the involvement of a broad range of stakeholders, was designed to increase the credibility and balance of the published report. In 1988, for the first time, a Public Advisory Committee on SOE Reporting (PAC), comprising 10 Canadians from nongovernmental organizations, was created to provide strategic direction and advice. In addition, federal participation increased from two to eight agencies. From 2 main authors in 1986, the number of authors and main contributors expanded to 100 experts from all stakeholder groups. To enhance accuracy and credibility, the number of internal and external reviewers was increased. In total, 99 external peer reviews were solicited to complement about 100 reviews by federal experts.

The 1991 report was the result of a strategy in which the process was as important as the product. The involvement of so many stakeholders resulted in a more complete, balanced, and credible document than could have been produced by any single organization. The final product was a 750-page book with 27 chapters covering human activities, environmental components, regional case studies, and priority issues.

The State of Canada's Environment — 1991 was a Canadian best-seller, selling over 5 000 copies in only three months. Over half of Canadian colleges and universities have used the 1991 report as a resource document or required text. In 1996, the press run of 20 000 copies of the 1991 report is virtually sold out.

As work began on the third national report, additional changes in both contents and process were driven by an extensive evaluation of the 1991 report, the need for a holistic approach, and reduced resources.

The goal remained the same as it had been for the 1991 report: that is, to provide timely, accurate, and accessible environmental information, integrated with socioeconomic factors, to improve decision-making and support progress towards sustainability.

Likewise, those who prepared both reports accepted four fundamental goals:

1) to advance the concepts associated with SOE reporting;
2) to advance SOE products;
3) to create a report that would meet client needs; and
4) to achieve credibility through the involvement of a broad range of stakeholders.

1) Advancing the Concepts Associated with SOE Reporting

Since 1991, many provinces and territories have contributed their own advances to SOE reporting. As part of the government's overall efforts at harmonization, the managers of the third national report have tried to ensure that concepts, indicators, and data in the 1996 report are compatible with those in use within other jurisdictions and organizations that currently share responsibility for and interest in the environment.

Recently, both within Canada and internationally, there has been a strong movement towards sustainability as a priority for governments. Thus, advances in defining and measuring sustainability, reflected in such widely used documents as *Caring for the Earth* (1991, the updated version of the 1980 World Conservation Strategy) and *Agenda 21* (1992), had to be incorporated into the conceptual framework of the 1996 report, which is a combination of three elements, as outlined below:

a) An ecosystem approach

For the purposes of the 1996 SOE report, an ecosystem approach is defined as a comprehensive and holistic assessment of the state of the environment. This approach recognizes the complexity of ecosystems, emphasizes that people are indeed part of ecosystems, and adopts ecozones as spatial reporting units.

Such an approach examines the interconnections within and among component parts. Interactions can occur (1) among elements within a single ecozone, (2) between ecozones, (3) among environmental components and human activities, and (4) among social, economic, and environmental elements. Throughout the report, an effort is made to document such interactions.

b) Requirements for sustainability

Sustainable development can be defined as activities that meet the needs of the present without compromising the ability of future generations to meet their own needs. Although debate on definitions continues, there is growing understanding of the social, economic, and environmental conditions necessary for sustainability. To be useful as a tool for informed decision-making, an SOE report must measure progress towards this objective.

According to recent work, such as *Caring for the Earth*, *Our common future* (the Brundtland report), and *Agenda 21*, some key requirements of sustainability are as follows:

Environmental objectives

- Maintenance of life support systems;
- Preservation of biological diversity; and
- Maintenance of the productive capacity of species and ecosystems.

Economic and social objectives

- Efficient use of nonrenewable resources;
- Improving the quality of human life; and
- Protecting and promoting human health.

This report addresses sustainability mainly from the environmental perspective. It is intended to complement ongoing work by Health Canada and Statistics Canada in advancing our ability to gauge progress towards the social and economic objectives of sustainability. Thus, the 1996 SOE report uses life support systems, biological diversity, and productive capacity as benchmarks against which environmental conditions and changes can be interpreted.

c) The four SOE questions

Feedback from readers of the 1991 report indicated that answers to the four SOE questions corresponded to the information that they sought. Consequently, those preparing the 1996 report retained this approach. This ensured that clients' needs were met and that a measure of continuity with the previous two reports was maintained. However, a fifth question was added to make a more direct link with sustainability:

- Is this sustainable? (are human actions depleting environmental capital?)

2) Advancing SOE Products

As client needs changed, SOE reporting products had to keep pace. For the first time, *The State of Canada's Environment* is available on the Internet's World Wide Web, and the CD-ROM of the 1996 edition will be more widely available than was the prototype 1991 CD-ROM. Both the Internet and CD-ROM versions have advanced query or search capabilities that enable users to quickly locate information in the report using single or multiple keywords. Every occurrence of the keywords in the text or tables of the entire report can be readily located. Owing to space, time, and cost constraints, this print version of the report does not include an index, and clients are encouraged to explore the search capabilities of the electronic products.

In addition, international organizations, other countries, and some other Canadian jurisdictions and agencies now regularly produce SOE reports that help to meet the information needs of Canadians.

3) Meeting Clients' Needs

The response of over 2 000 purchasers of the 1991 SOE report to a user's survey provided a clear indication of their information needs and preferred formats. Approximately 97% of respondents to the survey indicated that the organization of the 1991 report met their needs and that the different regional, national, and issues perspectives had to be retained. It was critical to respond to readers' demands, retaining the best elements, while adding topics and elements they felt were missing in 1991.

Similarly, as over 90% of those purchasing the 1991 report indicated that they did so for partly or entirely work-related reasons, it is clear that there is tremendous potential for bringing environmental considerations into the decision-making process of business, government, and other sectors. The 1996 report had to meet the information needs of these users.

The challenge was to strengthen the ecosystem approach while keeping the contents accessible to users. Readers valued the ease of accessing information at different geographic scales (local, regional, national, and global), with the regional case study chapters being particularly popular. An ecological approach recognizes that different levels of integration are required for a holistic perspective. Thus, the structure of the 1996 report focuses on these different levels and the interactions among them.

Part I — Ecosystems and people

- Sustainability is identified as an overall goal, and some criteria for measuring sustainability are presented.
- The ecosystem approach is introduced and the complexities and interactions within and among its components are described.
- Canada is set in a global context.

- A chapter about Canadian lifestyles recognizes that people are part of ecosystems and that individual actions have effects at every level, from local to global.

Part II — Canadian ecozones

- The 15 terrestrial and 5 marine ecozones in Canada, first used in the 1986 report, have been grouped into 7 units for the purpose of the 1996 report and its nonspecialist audience.
- Each chapter describes the biophysical characteristics of an ecozone or group of ecozones, explains the effects of human activities on those ecozones, and assesses the sustainability of the overall ecosystem.
- The authors have tried to integrate social, economic, and environmental considerations, while recognizing the need for trade-offs.
- Each chapter highlights the particular issues and/or linkages of particular concern in that area.
- In many cases, the text identifies data gaps that prevent conclusions about the nature of linkages between human activities and environmental trends.

Part III — National overviews

- These chapters integrate information on air, water, land, and biota, as well as human activities, for the country as a whole.
- Chapters on environmental components, human activities, and urban areas emphasize interaction within and among social, economic, and environmental elements.
- Presentation of data by province and territory, where appropriate, complements the presentation by ecozone in Part II.

Part IV — Canada in the global context

- These chapters examine how individual and collective actions have implications at the ecosphere scale.
- The focus is on three key issues that are important to Canadians and all global inhabitants.
- Each chapter emphasizes Canada in a global setting and attempts to assess the sustainability of human activity and the environment.

Part V — Towards environmental sustainability

- Similar to the 1991 report, a concluding chapter summarizes the book's findings in relation to the goal of sustainability.

4) Enhanced Credibility

Credibility of such a report depends on the involvement of many experts. Although more *federal* organizations had been involved with the 1991 report than with the 1986 edition, there was justifiable criticism from some *provincial* authorities and *nongovernmental* agencies regarding their limited involvement. As a result, the participation of such partners in the preparation of the 1996 report was broadened considerably.

Two key initiatives were developed specifically for the 1996 report. First, a State of the Environment National Network was established to increase the involvement of federal, provincial, and territorial agencies. The national network comprised a single contact within each of 14 federal and 12 provincial/territorial government departments. The main task of the representatives was to orchestrate their agency's contributions in the form of expertise, data, information, advice, and reviews for the whole report. This enabled the project to draw upon existing government committees and mechanisms and to tap into their constituencies, such as industry associations, federal/provincial committees, other provincial departments, provincial round tables, and Aboriginal groups.

Second, each chapter of the report was completed under the direction of either a formal Chapter Coordinating Committee or a more informal but similar mechanism. Such groups, comprising the key federal, provincial, territorial, and nongovernmental stakeholders, were the driving force behind the preparation of each chapter. This initiative addressed the wish of stakeholders to be involved earlier in the process of preparing the report.

Regardless of the mechanism used for the chapters, each manuscript followed a similar production process. The basic steps of research, manuscript preparation, review, editing, and technical production are outlined below. As can be seen, the foundation of the 1996 SOE report was laid with the final evaluation of the 1991 report.

Critical Path for the 1996 Report

Evaluation and consultation

- Evaluating the 1991 report and consulting stakeholders were critical first steps in producing a credible exercise as well as a credible document in 1996. Steps included:
  - 18 external commissioned reviews;
  - assessment by former and current members of PAC;
  - interviews with federal participants to obtain their feedback;
  - 2 000 responses to a user's survey;
  - consultations with every province and territory and selected nongovernmental groups;
  - analysis of cost overruns and production problems;
  - analysis of sales statistics;
  - analysis of media coverage and use;
  - unsolicited input from stakeholders; and
  - ongoing strategic direction and review by PAC.
- Together with operational considerations, these steps helped determine the table of contents and production process.

Negotiation and production

- Compared with the 8 federal departments involved in the 1991 report, formal commitments to contribute to the 1996 report were received from deputy ministers in 14 federal agencies and 12 provincial and territorial governments.
- In addition, an increased number of nongovernmental organizations from all stakeholder groups were formally involved in the report's preparation.

- Each chapter was prepared under the guidance of a Chapter Coordinating Committee or similar mechanism made up of selected stakeholders and chaired by a State of the Environment Directorate (SOED) coordinator.

Review and revision

- Once drafted, manuscripts were reviewed first by committee members and subsequently by SOED, agencies with representation on the committee, and technical experts. Drafts went through as many iterations as necessary and appropriate within the time frame, including external review by experts not otherwise associated with the preparation of the chapter. The involvement of over 70 external reviewers added immensely to the report's credibility.

Publication and distribution

- A team of environmental writers/editors was hired to ensure consistency and a style appropriate for the target audience. After editing, each Chapter Coordinating Committee or equivalent reviewed its chapter for accuracy. Translation and editing in the other official language followed.

- Marketing strategies and new electronic technologies were investigated and new partnerships forged to allow for the release of the report on the Internet, on CD-ROM, and in an on-demand print format.

SOE Reporting and the Goal of Sustainability

With the benefit of experience with two previous reports and feedback from both participants and users, the organizers of the third national SOE report strived to improve both process and product. Unfortunately, a counterbalancing trend also came into play. Across Canada, resources devoted to SOE reporting were reduced. Throughout provincial, territorial, and federal agencies and nongovernmental groups, once-firm commitment to SOE reporting yielded to hard economic reductions. Databases were not maintained to the same level, data sharing was reduced, and interpretation of data was more difficult to obtain. Thus, the broad, participatory process for this project was severely tested.

However, although budgets and staff resources were reduced, Canadians' expectations of a truly national, comprehensive SOE report remain unchanged. In fact, the need for environmental reporting to contribute to the objective of sustainability has never been greater.

Living in relative affluence among seemingly abundant natural resources, the "average Canadian" has adopted a lifestyle that takes the business of "consuming" very seriously. Every day, he or she uses the equivalent of nearly 24.64 L of gasoline, the most energy per capita of any country; withdraws 360 L of water for household use alone, helping to make Canada the world's second largest user of water per capita; and throws away about 1.8 kg of residential waste, assuring Canada's place among the leading "garbage producers" on a global basis. Indeed, for everyone in the world to live this way, it has been estimated that three planets would be needed to meet the demands for resources. Clearly, this is not sustainable.

Furthermore, as this third national SOE report indicates, we are not yet fully able to assess the sustainability of either our activities or the environment. Given these circumstances, environmental reporting remains an essential element in trying to achieve the goal of sustainability.

ACKNOWLEDGEMENTS

Canada has developed a tradition of broad participation for national environmental reporting. In keeping with this tradition, *The State of Canada's Environment — 1996* is the result of a complex, consultative process involving hundreds of Canadians. Indeed, the process of preparing this report has been as important as the final document itself; for, in coming together to share data, information, and perspectives, the contributors have strengthened the collective national understanding of Canada's environment.

Chapter Coordinating Committees, comprising key public and private stakeholders with knowledge of the places and issues covered by the chapter or section, directed the nongovernment consultants who prepared most of the drafts. Guided by the conceptual framework for the report and chapter templates, each committee determined the table of contents for its chapter, provided data and information, reviewed drafts, circulated drafts to a wider circle of reviewers, and generally oversaw the preparation of the chapter. A member of the staff of Environment Canada's State of the Environment Directorate (SOED) chaired each committee. Committee members are named in the acknowledgements at the end of each chapter. We are indebted to each of them for contributing their scientific knowledge, analytical skills, and diverse perspectives to this report.

PUBLIC ADVISORY COMMITTEE ON STATE OF THE ENVIRONMENT REPORTING

Since 1988, a Public Advisory Committee on State of the Environment Reporting (PAC) has advised Environment Canada and Statistics Canada. Comprising 10 individuals from environmental organizations, academia, and the private sector, the committee contributed greatly to the conceptual framework, structure, and contents of the 1991 and 1996 reports. During their 3-year terms, members monitored progress, commented on methodology, and reviewed chapters or components. Gratitude for their guidance is extended to the following individuals:

Chairs

Dr. Nancy Olewiler (1994–95)
Department of Economics
Simon Fraser University
Burnaby, British Columbia

Dr. George Francis (1991–94)
Department of Geography
University of Waterloo
Waterloo, Ontario

Prof. Peter Jacobs (1989–91)
Faculté de l'aménagement
École d'architecture du paysage
Université de Montréal
Montréal (Québec)

Members

Dr. Roberta Bondar
Faculty of Kinesiology
University of Western Ontario
London, Ontario

Dr. Raymond Brouzes
Alcan Aluminum Ltd.
Montreal, Quebec

Ms. Janice Harvey
Conservation Council of New Brunswick
Fredericton, New Brunswick

Ms. Doreen Henley
Canadian Manufacturers Association
Ottawa, Ontario

Dr. R.A. (Tony) Hodge
Victoria, British Columbia

Mr. John Lilley
Canadian Society of Environmental Biologists
Sherwood Park, Alberta

Mr. Rob Macintosh
Pembina Institute for Appropriate Development
Drayton Valley, Alberta

Ms. Inka Milewski
Conservation Council of New Brunswick
St. Andrews, New Brunswick

Dr. William Rees
School of Community and Regional Planning
University of British Columbia
Vancouver, British Columbia

Ms. Judith Smith
Torrie Smith Associates
Orleans, Ontario

Mr. Carl Sonnen
Informetrica Limited
Ottawa, Ontario

Ms. Kelly Anne Steinhauer
Memorial University of Newfoundland
St. John's, Newfoundland

Dr. Moire Wadleigh
Department of Earth Sciences
Memorial University of Newfoundland
St. John's, Newfoundland

COMMISSIONED REVIEWERS

To complement the 34 external reviews provided by PAC members, more than 40 additional external peer reviews were commissioned from recognized experts outside government. The thoughtful comments received from the commissioned reviewers increased the balance, accuracy, and completeness of the report. Acknowledged at the end of each of the chapters that they critiqued, these experts were instrumental in providing Canadians with an authoritative report.

STATE OF THE ENVIRONMENT NATIONAL NETWORK

To ensure that all appropriate federal, provincial, and territorial agencies were involved and to capitalize on existing intergovernmental mechanisms, a national network for *The State of Canada's Environment — 1996* was established. In total, 14 federal organizations and all 10

provinces and two territories responded to the invitation to participate.

Each organization designated one or more representatives (1) to serve as the official point(s) of contact for all matters relating to the 1996 National SOE Report, (2) to finalize tables of contents for specific chapters, (3) to coordinate their agency's headquarters and regional input to specific chapters, and (4) to guide all material through their organization's review processes. Fulfilling these obligations involved considerable liaising within their organization and with Environment Canada. Given the ongoing significant downsizing and reorganization at all levels of government, these responsibilities added to already heavy workloads. To the following people who served on the SOE National Network, appreciation is extended for their valuable contribution.

Provinces and territories

Alberta: Ms. Aniko Szojka-Pernell and Mr. Terry Zdan, Alberta Environment

British Columbia: Ms. Linda Hannah, Ministry of Environment, Lands and Parks

Manitoba: Ms. Tammy Gibson, Dr. Emil Kucera, and Ms. Laurie Streich, Department of Environment

Newfoundland: Mr. Tom Graham, Department of Environment and Lands

New Brunswick: Dr. Nabil Elhadi, Department of the Environment

Northwest Territories: Ms. Kathryn Emmett, Department of Renewable Resources

Nova Scotia: Ms. Frances Martin and Mr. Tim Smith, Department of the Environment

Ontario: Ms. Beverley Hanna Thorpe and Mr. John Stager, Ministry of Environment and Energy

Prince Edward Island: Mrs. Christine MacKinnon, Department of Environmental Resources

Quebec: Monsieur Roger Lemire, Ministère de l'Environnement et de la Faune

Saskatchewan: Ms. Lynda Langford and Ms. Laura Lawton, Department of Environment and Resource Management

Yukon: Ms. Yvonne Harris, Department of Renewable Resources

Federal agencies

Agriculture and Agri-Food Canada: Ms. Christine Nymark, Environment Bureau

Atlantic Canada Opportunities Agency: Mr. Tom Babcock, Policy Development

Canada Mortgage and Housing Corporation: Mr. David D'Amour, Research Branch

Department of Canadian Heritage: Mr. John Carruthers and Mr. Tim Sookocheff, Parks Canada

Department of Fisheries and Oceans: Mr. Ken Yuen, Habitat and Environmental Sciences Directorate; and Dr. Gary L. Boyd, Fisheries and Oceans Science Directorate

Environment Canada: Mr. Bruce Angle, Mr. Rob Cross, and Mr. Rick Jones, Atmospheric Environment Service; Mr. Bill Appleby and Mr. George Coates, Environmental Protection Service; Mr. Steve Blight, Mr. John Eby, Ms. Nancy Harris, and Mr. Phil Kurys, Policy and Communications; Dr. Vic Bartnik, Mr. Donald Bernard, Dr. Art Martell, and Dr. Brian Wilson, Pacific and Yukon Region; Ms. Susan Eros and Mr. Gerald McKeating, Prairie and Northern Region; Mr. Simon Llewellyn, Mr. Darrell Piekarz, and Mr. Harvey Shear, Ontario Region; Mme. Lynn Cleary and Ms. Nicole Lavigne, Quebec Region; and Dr. George Finney and Mr. Hugh O'Neill, Atlantic Region

Federal Office of Regional Development (Quebec): Ms. Carol Collier, Interministerial Liaison

Finance Canada: Mr. Larry Weatherly, Economic Development Policy Branch

Health Canada: Ms. Patty Birkwood, Environmental Health Directorate

Indian and Northern Affairs Canada: Mr. Paul Cuillerier, Lands and Environment Branch; and Mr. Ricki Hurst, Northern Affairs Program

Industry Canada: Monsieur Lucien Bradet, Environmental Affairs Directorate

Natural Resources Canada: Mr. John Forster and Mr. Richard Côté, Canadian Forest Service; Mr. Glenn Kendall, Mineral Policy and Planning; and Mr. Alan Turner and Mr. Grant Macpherson, Energy Policy Branch

Statistics Canada: Mr. Michael Bordt, Mr. Craig Gaston, and Mr. Bruce Mitchell, National Accounts and Environment Division

Transport Canada: Mr. Robin Lewis, Intergovernmental Relations and Environmental Affairs

Western Economic Diversification: Dr. David LeMarquand, Executive Services

In addition to the above people designated as contacts for the SOE National Network, others within and outside of government made exceptional contributions to specific chapters or groups of chapters. These contributors are identified at the end of each chapter. Our thanks go out to all of them for their tireless efforts to enhance the quality of the report. Special thanks go to Dr. C.I. Jackson, who, in addition to providing insightful comments on many drafts, prepared introductory and concluding material for Parts III and IV.

Editors and Translators

When hundreds of scientists and contractors are involved in the preparation of a document consisting of over 450 000 words, the result is an editor's nightmare. To render so many different writing styles into a cohesive document is a challenge. We were fortunate to have the assistance of several extremely capable people. Susan Burns, Senior Scientific Editor with the Canadian Wildlife Service, along with Gary Ironside, of SOED, established the editorial procedures for the report. Susan served as Editor-in-Chief and coordinated the four talented editors who accomplished the daunting job of rendering the work of dozens of authors into a cohesive report.

David Francis, Lanark House Communications (Toronto), Jennifer Jarvis (Ottawa), and Jane Whitney (Ottawa) worked as a team to transform many diverse manuscripts into a form and language appropriate for a nontechnical audience. Elizabeth Sanborn of the Translation Service of Environment Canada made an important contribution to this process by overseeing the

translation of French source material into English. Marla Sheffer (Ottawa) was the copy editor who brought consistency to the 16 chapters and ensured a polished final product. Collectively, their eye for detail and accuracy and their editorial expertise ensured a highly readable report.

Working under tight deadlines, a group of dedicated translators and editors helped produce the French version of this report. Sincere appreciation is extended to Jacques Pellerin, Chief of Translation Services (Biology) of the Translation Bureau of Public Works and Government Services Canada. Special thanks also go to Annie Meyere, who coordinated the translation team, and to the following staff who translated numerous drafts and revisions of chapter manuscripts: Hélène Bernard, Jean-Blaise Bourque, Denise Campillo, Suzanne Chartrand, Maryse Chynchuck, Yves Desautels, Pierre DeTonnancour, Lynne Dwyer, Serge Gagné, Marie-France Guéraud, Michel Laliberté, François Lanctôt, Louis Panneton, and Robert Papineau. Marielle Racette, Director of Environment Canada's Translation Service at the start of the project, and her successor, Jocelyn Houle, were extremely helpful in orchestrating translation arrangements. Raymonde Lanthier (Repentigny) again served as the overall editor for the French edition. Her meticulous work and attention to quality were much appreciated. Raymonde supervised three additional editors who assisted with specific portions of the report: Madeleine Choquette (Ottawa), Normand Denis (Gatineau), and Guy Rivest (Aylmer). Our thanks go to all of them for helping to ensure a high-quality French edition.

Technical Production Personnel

The State of Canada's Environment — 1996 has been made available on the Internet and on CD-ROM, in addition to the print format version. Preparation of the electronic versions of the report necessitated the conversion of all text and graphics files into a format suitable for electronic media. This task was ably accomplished under difficult time constraints by Jason Flick, Brent Landry, and Scott FitzGerald of Libraxus Incorporated (Ottawa), Raymonde Durand of Graphics Plus+ (Ottawa), and Ron Gauthier, Rachelle Croteau, and Sandra Maxsom of the Knowledge Integration Division, Environment Canada.

Jean Racicot, Communications Airelle (Repentigny), produced the French version of the majority of the figures and tables. Banfield-Seguin Ltd. (Ottawa) provided design services for all versions of the report. The high technical standards of this print version of the report are due to the skills and commitment of two commercial firms. Macromedia Communications (Ottawa) adapted the original design provided by ImaGraph Systems and completed the electronic page layout under extremely tight deadlines. Gilmore Printing (Gloucester, Ontario) printed a high-quality publication in a very short time frame.

"Teacher's Place" Contributors

Another innovation in 1996 was the development of "Teacher's Place," a set of classroom activities that draws on information contained in *The State of Canada's Environment — 1996*. This package of teaching aids, aimed at the intermediate level but adaptable to lower and higher levels, was made available on the Internet and was included in the CD-ROM version of the report. The initiative was undertaken in collaboration with Canada's SchoolNet. A focus group of teachers from across Canada provided initial ideas for the project. Appreciation is expressed to Angela Couto, Emily Clark Dingle, Michèle Fréchet, Robena Maclaren, Peggy March, Tina McPhee, Joanne Meyer, Armando Teves, Paul Van Zant, and Wayne Wolsfeld. Assistance and feedback were also provided by Bill Bogers, Dickson Mansfield, and Patti Smith. Wanda James designed the page layout and provided the visual enhancements. Special thanks are owing to Kirsty Dickson, Cindy Hough, and Daniel Meritt, the three teachers who designed, developed, and diffused the Teacher's Place teaching activities.

State of the Environment Directorate

Senior managers provided vision and support throughout the report's preparation. Jim Collinson, former Assistant Deputy Minister, strongly advocated the use of an ecosystem approach and an ecological framework, and Ian Rutherford, Director General of SOED, provided a consistent vision and operational and moral support to staff, in addition to reviewing all chapters as part of the approval process.

Development of the ecosystem approach was spearheaded by Ed Wiken, Director of the Ecozone Analysis Branch, and his staff. Valuable contributions to the contextual framework and chapter templates were made by George Kowalski, Ian Marshall, Paul Quinn, Patricia Roberts-Pichette, Peter Rodgers, Paul Rump, and Ian Rutherford. In addition, Ian Marshall and Ed Wiken, working with Scott Smith (Agriculture and Agri-Food Canada) and other members of the Ecological Stratification Working Group, made a significant contribution in guiding the completion of the *National Ecological Framework for Canada*, which provides considerably more detailed background information about the terrestrial ecozones and ecoregions than was previously available.

Because the legislated mandate to prepare this report rests with Environment Canada on behalf of the federal government, the greatest responsibility fell to the staff of SOED who served as chapter coordinators. They established the Chapter Coordinating Committees or other consultative mechanisms, carefully choosing a combination of key stakeholders to represent the full range of perspectives. Chapter coordinators led the efforts to establish a table of contents; hired and supervised contractors; actively solicited data, information, and case studies; analyzed statistics; reviewed progressive drafts and provided detailed comments; coordinated the review process; undertook revision and writing of sections; worked with editors to ensure accurate texts; collaborated with graphic designers; proofread innumerable drafts and checked illustrations and references; and generally ensured the completion of chapters. Each

staff member also served as a technical expert for specific issues or ecozones, providing appropriate data and information to all other coordinators and reviewing drafts of other chapters. These tasks required hard work, sound scientific knowledge, and good organizational skills.

Chairing the Chapter Coordinating Committees and arbitrating amongst the strongly held and often divergent views required diplomacy, skill, and stamina. There was seldom unanimity, sometimes consensus, and always healthy debate. At times, enormous pressure was brought to bear on the coordinators. Their own organization was reduced by half during the early stages of the report preparation, and most would lose their own positions upon completion of the project. That this report was completed under such conditions is testimony to the individual commitment to the environment and collective professionalism of the following chapter coordinators:

John C. Anderson
Robert R. Audet
Wayne Bond
Harry Hirvonen
Gary Ironside
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Asoka Mendis
V. Neimanis
Dennis O'Farrell
Christian Pupp
Paul Quinn
Ken Redpath
John R. Reid
Tony Turner
E. Neville Ward
Ed Wiken

Such an ambitious undertaking required an overall coordinator to help move the project through its various stages. National Coordinator Paul Quinn's hard work and ability to remain calm and effective in the face of endless challenges were essential to coordinating the project and promoting consistency and quality throughout the report.

In a period of dramatic technological change, maintaining the SOE database and transforming complex and often incompatible data sets into meaningful and accurate information were challenging. The following team was responsible for data management and produced most of the figures and tables: Neil Spooner and Douglas Duggan, who worked to meet the requirements of chapter coordinators and coped with the inevitable problems and limitations of the data, and Nicole Cardinal, who prepared many of the graphics. Yvan Laframboise, Jean-Marie Viau, Raymond Ménard, and Tom Pierce also contributed technical support to the overall 1996 SOE report and related products.

The professional people who supported the researchers and managers were an integral part of the team. They maintained their professionalism and good humour over the duration of the project. Jim Moyes brought much-needed order to the many federal–provincial and Public Advisory Committee meetings. Jacquie Manchevsky contributed to the development and implementation of the marketing strategy. Danièle Goulet coordinated several stages of the technical production. Much appreciation for their efficiency and support is also extended to Gisèle Girouard, Lucie Lambert, Lise Lapointe, Michèle Larose, and Danielle Lavergne, as well as to Bina Deeljur, Denise Landry, Lynda Gravel, Nataly Longpré, and Manon Larocque.

Other SOED staff, although not assigned primarily to the preparation of *The State of Canada's Environment — 1996*, contributed through their ongoing work in related areas. Anne Kerr, Director of the Indicators Branch, and her staff provided the environmental indicator material for inclusion in the report. Janet Lamb, who was heavily involved in the review process, and Peter Rodgers applied the analytical capability of the indicators data management system to assist chapter coordinators throughout the preparation of the report.

Over the years, co-op students and others were most helpful in assisting staff with scientific research and the preparation of graphics and manuscripts. For their enthusiasm and energy and much needed support, appreciation is extended to Kirk Bergey, Jean Bjornson, Louis Cournoyer, Jean-François Gagné, Gabriel Gagnon, Brandi Lee Hicks, Ignace Kayijamahe, Guadalupe Mateos-Marcos, Meghan McKellar, Margery Moore, Stéphane Nourry, Matt Ordower, Lori Rivière, Subo Sinnathamby, Charles Stanfield, Jeremy Vink, and Geoff Woods.

As Chief of the Reports Division, Wendy Simpson-Lewis directed the work of the team of chapter coordinators and was the key person behind the development and implementation of the complex process required to coordinate the hundreds of individuals whose combined efforts ultimately led to the completion of final manuscripts. Her hard work, dedication to the highest standards, and constant focus on meeting the needs of clients set an example for everyone. Despite her heavy workload, Wendy herself wrote key sections of text. The report owes much to her boundless energy, detailed reviews of numerous draft manuscripts, writing skills, and sound advice.

It fell to Jean Séguin, Chief, Marketing and Production Division, to oversee publication of the report, Canada's most comprehensive environmental information base, on the Internet as well as on CD-ROM and in a hard-copy edition. He was a constant driving force in the development of innovative new approaches and the application of new technology for the report's production. Jean's enthusiasm, hard work, and vision enabled him to forge creative partnerships and do what had not been done before.

Ultimately, overall responsibility for the preparation and technical production of *The State of Canada's Environment — 1996* rested with Wendy Simpson-Lewis and Jean Séguin, under the direction of Rosaline Frith (Director, Reporting Branch). The success of the project required superior leadership to overcome challenges, to make difficult decisions, and to ensure that the ultimate goal was met. Although management responsibilities were shared by many of those involved, without the overall leadership provided by Rosaline, this report would not have been completed.

Collectively, all these people have made it possible for Canadians, whatever their requirement, to access more information more quickly than ever before. As Canada's third national SOE report, may it be a springboard to true progress towards sustainability.

THE STATE
of
CANADA'S
ENVIRONMENT

1996

PART I

ECOSYSTEMS AND PEOPLE

Chapter 1 Understanding Connections

Highlights

People are waking up to the fact that humans are an integral part of the Earth's interconnected ecosystems, not separate from them. Our success in maintaining the quality and productivity of the environment will depend on acknowledging this relationship and acting accordingly.

■

In the comparatively short time that humans have been on Earth, we have had a dramatic impact on the planet's ecosystems. Changes in the quantity of global resources have become obvious only in the last few decades. Before then, few people even thought about the supply of trees, soil, fish, or clean water. Trees were to be harvested, soils were to be ploughed, fish were to be caught, and rivers were to be dammed. Now actions that were once thought to be isolated are seen as having a web of wide-ranging consequences.

■

The human role in ecosystems differs from that of any other species in two ways. First, humans have the ability to drastically alter the ecosystems upon which they depend; secondly, humans are capable of greatly reducing or eliminating many of the factors that formerly limited their numbers. These capabilities can result in an intolerable pressure on natural resources and life support systems.

■

For development to be ecologically sustainable, its benefits must continue to be maintained indefinitely. The principle of sustainability must be widely applied if Canadians as well as people in other countries are to enjoy an acceptable quality of life in the future.

■

Environmental protection cannot be successfully accomplished in isolation from social and economic development. Regular monitoring and evaluation of all development activities and policies are essential to the achievement of sustainability.

■

CONTENTS

> *Sustainable development deals with interrelationships and linkages. It means looking at decisions in a holistic way where there is a parallel care and respect for people and for the enveloping ecosystem of which everyone is a part.*
>
> — Hodge et al. (1995)

INTRODUCTION

Why should Torontonians care about the Arctic? Why should Inuit in the Northwest Territories be concerned about the Russian heartland or the Mexican coffee belt? Why should residents of Vancouver be concerned about the Brazilian rain forests?

Canadians, like many people around the world, are becoming increasingly aware of the "shrinking" of the planet's seemingly vast distances and natural resources. The long-range transport of radioactive particles from Chernobyl to Labrador, the contamination of Arctic country foods by polychlorinated biphenyls (PCBs), the rapid spread of zebra mussels after their introduction in the Great Lakes, and the transport of acidic pollutants from industries in the northeastern United States to eastern Canada: all these recent events remind us that the consequences of human actions are not constrained by political boundaries. The declining populations of particular fish species and the increasing number of forested areas that we see logged are other reminders of how environmental resources are changing. Failure to understand the intimate connections between human actions and environmental impacts has led to serious social, economic, and environmental problems.

LIVING AT THE OUTER EDGE

Time, the Earth, and environmental information seemingly all share one characteristic — immensity. Time is limitless, the Earth is gigantic, and environmental information is plentiful. However, in terms of the well-being of people and the management of resources, this perception of immensity is now being recognized as false. Common sense — and the parade of serious environmental issues occupying the daily headlines — would indicate that we are pushing the capacity of many of the Earth's resources past their limits. Physically, and perhaps metaphorically, we are "living at the outer edge."

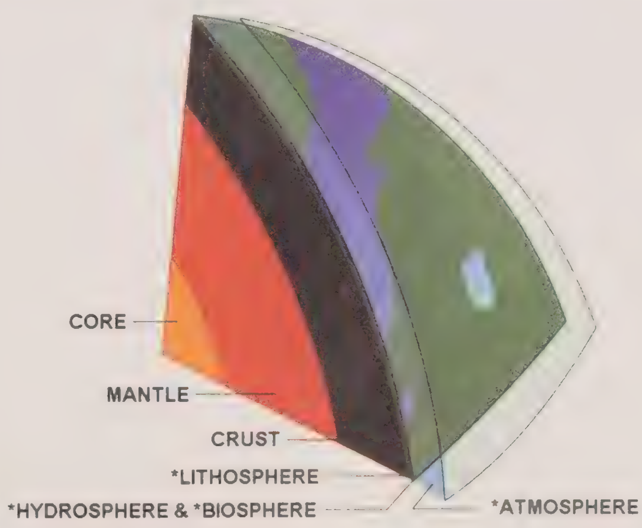
Earth and home

The immensity of the Earth — 6 717 700 000 000 billion tonnes in weight, 510 074 600 km^2 in area, 40 091 km in circumference, and 12 717 km in diameter (National Geographical Society 1966) — is difficult to comprehend. Strikingly, people and other living things are almost totally reliant on the very thin outer shell of the Earth — the ecosphere (Fig. 1.1). In fact, much of life is further restricted to the 25% of the outer shell's surface that is land (including both terrain and bodies of fresh water); the remainder of the thin layer is covered by oceans.

The human species has inhabited the Earth for approximately 3.5 million years — a mere 0.08% of the planet's 4.6-billion-year lifetime (Gardner 1989). If the Earth were 24 hours old, humans would have been present for about the last minute.

Throughout the Earth's history, periodic disasters and environmental changes have been brought about by the forces of nature. The advance and retreat of vast ice sheets during glacial periods wiped out countless species, volcanic eruptions have transformed landscapes, and floods have wreaked their havoc. In the very short time that humans have been here, however, the environmental changes have greatly accelerated. In North America, the near eradication of the bison in the late 1800s hastened the end of many traditional cultures. The dust bowl of the "Dirty Thirties" brought economic ruin to farming

Figure 1.1
The Earth's layers



Note: The ecosphere is composed primarily of the outer four layers, which are marked with an asterisk.

Source. After Fabun (1971)

communities across a large area of the continent. More recently, the emission of acidic pollutants has destroyed fish and other organisms in many lakes in eastern Canada and the United States. Worldwide, people are suffering from the consequences of ecological deterioration. About 1.3 billion people are without safe drinking water, close to 1 billion are suffering from hunger, and 13 million children die of starvation or infection each year.

Although our presence on the planet has been short, our awareness of past events is unlike that of any other species. We alone are capable of looking beyond the personal experiences of our own lifetimes and learning from the past. Historians and anthropologists have constructed an understanding of ancient cultures and civilizations, and scholars have reached back to eras when humans and other organisms did not even exist.

Inadequacy of information

Despite such knowledge, much remains to be learned about the Earth and our relationship with it. In Canada, governments and other groups have been gathering information about the environment for many years. But Canada is an immense country, covering 7% of the global land mass. Of all the countries in the world, Canada has the second largest land area — 9 215 430 km^2 — and the longest coastline: 243 792 km fronting on three oceans. Canada is also a diverse country, sparsely populated in most places and composed of many different ecosystems. Both its size and its diversity make the collection of environmental information a daunting task.

What environmental information does exist is spread among many specialized agencies, which typically focus on one aspect of the environment — for instance, wildlife, atmosphere, fresh water, or oceans. When this information is drawn together in an attempt to build an ecological understanding, the picture is surprisingly incomplete. There are problems with data quality, because different measurement techniques are used across the country. Long-term measurements are very important to assess the sustainable use of resources and ecosystems, yet few agencies have continuous, uniform records that go back more than 10 years. The purposes for which the environmental information was gathered over the years differ greatly, and the data may not be suitable for today's needs. For example, although scientists have been collecting and studying information on climate for decades, the information has not been collected in a way that enables the researchers to prove any change in climate beyond normal fluctuations. Clear and objective information is essential in any attempt to plan how we will manage environmental resources and human activities in the future.

Worrisome environmental issues

Phrases such as "forests of the future," "today's endangered spaces," and "nature for tomorrow" express apprehensions about the condition of our environment today and into the future. Like most other people of the Western world, Canadians are concerned about the state of the environment — about the ultimate impacts of their own and others' activities on the environment. Some of the questions that Canadians raise about their relationships with the environment seem relatively simple:

- Do we replant as many trees as we cut?
- Which wildlife species and habitats are threatened?
- Is the climate changing?
- What is the status of the stratospheric ozone layer?
- Are we protecting enough natural areas?
- Are air pollution and water pollution getting worse?

Other questions are more complex:

- How sustainable are Canada's renewable resources?
- What is needed to maintain the health and integrity of major terrestrial and aquatic ecosystems?
- How do we balance social, environmental, and economic interests in areas that are important for forestry, agriculture, mining, and fisheries?
- To what degree are Canada's environment and resources being affected by air and water pollution from other countries?

Simple or complex, these kinds of questions show that people are worried about the present impacts of human activities and aware of the need to improve how we plan and manage environmental resources in the future. The scope of the concerns extends beyond environmental issues to matters that affect our health and our socioeconomic well-being.

This state of the environment report looks at these issues from a comprehensive national perspective. Much of the report is devoted to addressing national concerns or regional questions that have national significance. Environmental reporting done at provincial and municipal levels or for specific sectors complements the national picture. In general, the report attempts to answer the following questions:

- What is the status of the environment?
- What is the significance of changes in environmental conditions?
- What is causing these changes?
- What is being done to correct problems or to sustain resources?
- What will be the outcome in the future?

Answering these questions will require a greater degree of ecological knowledge than has been available to date. Industries, governments, and individuals will need to continue their efforts to build a more comprehensive approach, to enable them to predict the effects of ongoing activities, to determine which activities are sustainable, and to guide their actions in the future.

A Holistic View of People and the Environment

In the past, the environment was usually thought of as being external to our lives, as something "out there": a pool of resources to provide us with food, clothing, and shelter. We used the environment's resources to benefit humankind, and the success of that

exploitation was often taken as a measure of progress. Throughout the world, resources — land, water, fish, trees, and animals — were managed and used in isolation. Now, it is increasingly apparent that, one way or another, all of these things are interconnected. The use of one environmental resource always has some immediate or long-term impact on the status of another resource or ecosystem.

Moreover, having once looked at the natural environment as something apart from ourselves, to be exploited or overcome, we now see ourselves much more as an integral part of it. We are part of an interactive global ecosystem — the ecosphere. Success in maintaining the quality and productivity of our environment will depend on acknowledging this relationship and acting accordingly.

The world's population has multiplied almost fivefold since the early 1900s. During the same period, the world's economy has grown by 20 times, the consumption of fossil fuels by 30 times, and industrial production by 50 times. The World Commission on Environment and Development (1987) has forecast that world industrial activity could multiply by an additional 5–10 times, given that many countries have yet to complete the industrialization process.

Such figures hint of profound impacts upon the ecosphere, as the world's people continue to invest in houses, transportation, and industries. Ecosystems have finite productive capacities and abilities to assimilate disturbance. The potential for disturbance becomes magnified as the population grows, resulting in greater demands being placed on energy supply and on ecosystems. To come to grips with this situation, the global community has advocated that a holistic approach be followed, whereby environmental, social, and economic systems are collectively considered throughout decision-making processes (IUCN et al. 1980, 1991; UNCED 1992). The conservation of basic life support systems, the long-term sustainability of species and resources, and the acknowledgement of fundamental relationships between people and the environment are key elements in this approach.

What is an ecosystem?

The prefix "eco" comes from the Greek word for a house. The source of the word is a reminder that ecosystems are the places where we live — our home. Like homes, ecosystems need to be cared for as a whole rather than by their parts.

Ecosystems can be described in different ways: as natural, modified, cultivated, built, or degraded. Native prairie grasslands are natural ecosystems, a forest that has been selectively logged is a modified ecosystem, a wheat field or an orchard is a cultivated ecosystem, and a town or city is a built ecosystem. Any ecosystem can become degraded. A heavily polluted wetland whose natural productivity has been reduced to an insignificant level is an example of a degraded ecosystem.

Whether ecosystems are heavily modified by human activities or remain in a natural wild state, they can be thought of as hierarchical. For ease of understanding, we may visualize a number of smaller ecosystems as nested within larger ones, as systems within systems. At the highest level in the hierarchy is the global ecosystem — the ecosphere. In the middle are large oceanic and terrestrial systems — for example, the 15 major terrestrial ecosystems that have been defined for the North American continent (Fig. 1.2). Each of these units in turn can be subdivided into smaller ecosystems. The boundaries between ecosystems are not like property lines or international borders; each line on the map represents the general area where one ecosystem unit merges with another.

Ecosystems appear as relatively self-sustaining units. Each has a fairly distinctive geographical setting and its own particular complement of plants, animals (including humans), and other organisms, together with air, water, soils, and rocks. The Arctic ecosystem, for example, has a set of biological and physical characteristics that have endured in relative constancy over time: frozen soils, frost-patterned ground, icebergs, cold climates, and Arctic flora and fauna (see Chapter 9). These components interact over time with one another: organisms draw nutrients from soils and water, the nutrients are circulated among organisms in a food chain, and finally the elements return to the air, land, or water; energy radiated from the sun flows through the system and is eventually lost back to space as heat; and so on.

Despite their self-sustaining appearance, ecosystems are not isolated from surrounding or even distant systems. Ecosystems interact with other ecosystems through a web of different relationships. Arctic fauna such as Caribou and Snow Geese migrate south to more temperate regions in the winter, Arctic waters circulate through the Pacific and Atlantic oceans, Arctic rivers may have their source in the boreal, taiga, or prairie ecosystems, and Arctic weather fronts circle the pole and penetrate more southerly locations.

The underlying ecological processes that drive various ecosystems may be invisible or obvious. Phenomena such as ocean currents, soil weathering, nutrient cycling, predator–prey relationships, and the decay and renewal of organic matter are like hidden processes rebuilding the ecosphere. Other ecological processes are more visible — such as massive floods and volcanic eruptions. In the absence of significant human intervention, large-scale ecological changes are normally so slowly paced that it is appropriate to think of ecological processes as naturally sustainable. It is upon this relative stability that the survival of both species and life itself has always depended.

Human alteration of ecosystems

Human activities are increasing the pace of ecological change and dramatically altering ecosystems. Years ago, the supplies of resources in relation to human numbers were generous, and people never dreamed that parts of the world's oceans could be fished out or that the vast expanses of forests might diminish. Few people even thought about the supply of trees, soil, fish, or clean water. Given such wealth of pristine resources, our dependence on them did not seem to be a problem. Even the quality of most of the environment did not seem at risk. Only recently has the critical

Figure 1.2
North American terrestrial ecosystems

Source: After the Commission for Environmental Cooperation Working Group on Ecological Regionalization.

state of both the quantity of global resource stocks and the quality of the environment become widely apparent.

Changes in the quantity of global resources have become obvious in the last few decades. Now it is hard to ignore the decline in old-growth forests, productive topsoil, fish stocks, and sources of unpolluted water. The Carolinian forest that once covered much of southern Ontario has been reduced to small isolated fragments. Agricultural and urban land uses have converted much of this former forested landscape. Over 15 000 lakes in eastern Canada are dead because of acidic pollutants (see Chapter 10), and the rate of extinction of certain species parallels that of the dinosaurs (see Chapter 14). A striking example of the interdependence of humans and their environment is the recent collapse of the east coast cod fishery — with its dramatic social and economic consequences (see Chapter 11).

Changes in the quality of the environment, such as increased carbon dioxide levels in the atmosphere and pollution of lakes and rivers, have largely been produced by the human quest for development. For a long time, development was seen simply as the process of modifying the environment to satisfy human needs and aspirations more fully. Trees were to be harvested, soils were to be ploughed, fish were to be caught, and rivers were to be dammed. The effect on the environment was seldom considered; nor were the relationships among these activities recognized. However, actions that were once thought to be isolated are now seen as having repercussions that are regional, national, and even global in scope (Fig. 1.3). Maintaining water quality to protect human health and aquatic life, for instance, depends on recognizing the impacts of wide-ranging activities and processes. The discharge of industrial waste, disposal of community waste, siltation from forest and agricultural practices, and pollution from mines need to be adequately managed to ensure that aquatic ecosystems around the globe are protected.

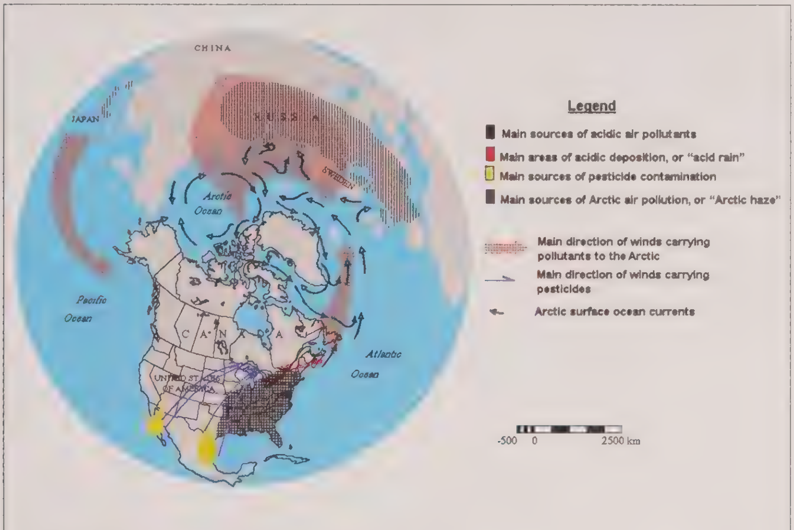
As the diversity of flora and fauna continues to diminish (see Chapter 14), and as air, water, and soil continue to be polluted, the environment is becoming increasingly impoverished. How are we going to reverse, or at least halt, this trend?

An ecosystem approach

These environmental concerns suggest that we need to be guided by a whole Earth ethic, or an ecosystem approach, which recognizes that decisions and actions must consider the whole system. Such an approach is necessary for very practical reasons. You cannot manage Arctic wildlife, for example, if you do not understand both the environment of which the wildlife is a part and the human activities that affect the environment (see Chapter 9). Living within the limits of the prairie ecosystem depends on understanding the fundamental character of the system: our failure to understand both the fundamental characteristics of the prairie ecosystem and the basic relationship between the climate and the soils of that area was what created the dust bowl. The dependencies that exist within and among ecosystems — all the connections among biological and physical components and essential life-supporting processes — must be considered in decision-making.

The ecosystem approach is a powerful concept for planning and managing human activities, but it is not enough. It must be complemented by ethical principles that respect the welfare of ecosystems, other organisms, and other people (Box 1.1). Together, the ecosystem approach and adherence to ethical principles can provide a realistic basis for renewed attitudes and practices to safeguard the future of the Earth.

Figure 1.3
The "attack" by acid rain, pesticides, and Arctic haze on the North American continent



Source: State of the Environment Directorate, Environment Canada.

People as part of ecosystems

Although the human species is clearly separated from others by characteristics based on intellect, the role of people in ecosystems may be viewed as essentially the same as that of any other species. People rely on clean air, soil, and water and a continuing supply of plant and animal products. They convert some of what they consume to meet their own physiological requirements and discharge wastes, which become part of the Earth's great cycles of decay and renewal.

There are, however, two important differences between the human role in ecosystems and that of other species. The first is the ability of humans, unmatched by any other species, to bring about drastic changes to the ecosystems upon which they depend. These changes, which usually result in a decrease in the natural productivity of ecosystems and which are often irreversible, are occurring at an increasingly rapid rate. Consider, for example, how much our world has changed because of motor vehicles and the industries and infrastructures that have grown up to support them (see Chapters 2, 11, and 12).

The second difference is that humans, unique among species, have been able to moderate the factors that formerly limited their numbers, such as famine, disease, and war. Success in dealing with these factors has contributed to the ever-expanding world population. Unless we can reduce the overall impact of humans on the environment, population growth will put increasing pressure on natural resources, life support systems, and socioeconomic systems.

Of course, human beings also have the power to recognize the problem and to do something about it. In this respect, technology is a formidable tool. It is technological development that underlies the human capacity to make a lasting impact on the environment, but technology itself is neither good nor bad. If it is misguided or poorly understood, a technology may have serious negative consequences. Informed by ecological understanding and appropriately applied, it can reduce the pressures that people impose on ecosystems.

Box 1.1
Ethics and the state of the environment

The environment is something in which all people share a common interest and by which all may be affected. Not surprisingly, ethical questions are at the heart of many environmental issues.

Ethics refers to the principles that define a person's duty to other persons and, indeed, to other living things with which we share this planet. Such principles are based on respect for the rights and welfare of other people, including those whom we may never meet and those who are as yet unborn. It is in accordance with ethics that people decide if an action is right or wrong.

Socioeconomic development that affects the environment and sometimes entire ecosystems therefore also has ethical dimensions. Decisions about development are usually based on estimates of the present and future costs and benefits to society. Such assessments take into account the likely environmental, economic, and social effects. To assess options, every effort is made to define effects in measurable terms and to identify who may gain and who may lose. Such a process is an indispensable means of assembling relevant information and can provide an invaluable basis for identifying the ethical dimensions involved.

However, many ethical issues cannot be quantified. It is difficult to fit ethical factors into the conventional framework of environmental decision-making in the same way as more tangible factors such as economic and biophysical data. What is necessary, then, is for people to consider the broad implications of any development: whether, on balance, a proposal or project is right or wrong in respect of its present and future impacts on other people, on other species, and on ecosystems. Access to full and accurate information about the development and about experiences with similar activities will guide people in deciding about the options that are available. Views on ethics are an essential supplement to the hard, measurable data in the decision-making process.

Technology can sharpen our understanding of the environment and of the processes of development. The ability to monitor the depletion of stratospheric ozone is an example (see Chapter 15). Being able to link that depletion with both human causes and subsequent health risks reinforces global awareness that people are an integral part of ecosystems. It illustrates that the human species is ultimately subject to the same constraints as any other living creature and that interdependence is the rule. Knowledge of this interdependence leads us to ask, in respect of every action we contemplate: What are the short-term and long-term effects? Is the action sustainable?

Understanding Sustainability

Guiding principles

In general, the terms *sustainable development* and *sustainability* are used to describe pathways to achieving a just, comfortable, and secure future: goals to which everyone aspires. However, like other suddenly fashionable words and phrases, the terms are sometimes misunderstood and misused. If Canadians are to fully adopt the principles behind these terms, they should start from a common understanding of what the words mean.

Sustainable development has been defined as "improving the quality of life while living within the carrying capacity of supporting ecosystems" (IUCN et al. 1991). Achieving sustainable development includes taking an ecological approach, knowing the importance of life-supporting ecosystems, and staying within carrying capacity. The concept of applying sustainable development worldwide is relatively new. While few would deny its logic as a global goal, applying the concept calls for the integration of effort and cooperation among nations, organizations, and individuals. National and provincial round tables, international summits, and government–industry forums on sustainability are all important mechanisms for encouraging increased cooperation (Box 1.2). There is also consensus that the science underlying environmental decision-making must grow as well.

Box 1.2
Canada contributes to the concept of sustainability

The concept of sustainable development was first given wide currency in 1980 by the World Conservation Strategy (IUCN et al. 1980), which defined conservation in the context of the management and use of the ecosphere. The goals were to maintain the greatest number of sustainable benefits for present generations and not to jeopardize the potential of the ecosphere to meet the needs and aspirations of future generations. These goals have been echoed and elaborated on in many subsequent publications:

- Our common future, *sometimes referred to as the Brundtland report (World Commission on Environment and Development 1987), presented the core ideas of sustainable development and sustainability.*
- Caring for the Earth *(IUCN et al. 1991) further stimulated discussion.*
- Agenda 21 *(UNCED 1992) was adopted at the Rio de Janeiro Earth Summit.*

Collectively, the above meeting and reports have boosted awareness of the need to balance environmental and developmental concerns.

The concept of sustainability has thus evolved quite rapidly. Canada and individual Canadians have been closely involved in the process:

- *Canada is a state member of the World Conservation Union (formerly the International Union for the Conservation of Nature and Natural Resources, or IUCN), which was the lead agency in the preparation of the World Conservation Strategy.*
- *In 1985, during the preparation of its report, the Brundtland Commission held public hearings in most Canadian regions. Many citizens and public officials had an opportunity to take part and to help shape the report.*
- *Environment Canada supported the IUCN-sponsored Conference on Conservation and Development (Jacobs and Munro 1987), held in 1986 to review and evaluate the World Conservation Strategy. This led to a decision to prepare a more broadly based version of the strategy, resulting in the publication of* Caring for the Earth *several years later.*
- *In Canada, the establishment of national, provincial, and territorial round tables on the environment and the economy during 1989 and 1990 was an important response to the Brundtland report. The round tables provide a forum to discuss cross-sectoral issues that could have a significant influence on the activities of government and industry.*
- *Finally, Canada was an active player in the preparations for the United Nations Conference on Environment and Development (UNCED), which began in 1989. The conference culminated at the Earth Summit in Rio de Janeiro in 1992 with the adoption of Agenda 21 and the opening for signature of the Framework Convention on Biological Diversity and the Framework Convention on Climate Change. The Earth Summit was attended by more than 100 heads of government, including Canada's prime minister, and was the most visible expression of international awareness of sustainability that the world has ever seen.*

How can development be sustainable? To many people, coupling the two terms is simply contradictory. To appreciate the concept, development needs to be thought of as the progressive betterment or improvement in the state of affairs. The products of development are people who are healthy, well nourished, clothed, housed, engaged in productive work, and able to enjoy leisure and recreation. Development includes a diverse range of activities or processes that increase the capacity of the environment to meet human needs, to improve the quality of human life, and to protect and maintain basic life support systems. Thus, development includes many traditional activities,

Box 1.3
Three Earths

An ecological footprint is a dramatic metaphor. It is used to describe the often unknown demands and impacts that human activities have on ecosystems. Most people in a city, for instance, tend to judge the environmental impacts of their community based on the extent to which buildings, roads, industrial areas, and houses spread over the landscape. However, the notion of a "footprint" looks at the broader and often hidden dimensions. Much of the work involved in determining the footprint is aimed at estimating the "carrying capacity." This could be interpreted as, for example, how much land it would take to produce all the goods and services that are used by people living in a city. Although it is impossible to take every factor into account, and although the calculations are complex, even a rough cast of the imprint can be revealing.

One such estimate of an ecological footprint concerns the residents of British Columbia's densely populated Lower Mainland region. To satisfy only consumption and waste assimilation needs related to energy, food, and forest products, the people in that area would require an area 19 times the size of their region. If this standard of living were extrapolated for the world's population, an additional "two Earths" would be required (Wackernagel and Rees 1996).

such as the extraction and processing of resources, the establishment of infrastructure, and the buying and selling of products. However, it also includes scientific research, improvements in technology, nature conservation, improvements in environmental management, support for the arts, health care, social security, education, and many other activities.

For development to be sustainable, its benefits must be maintained indefinitely. This means that, on balance, there must be nothing inherent in the process or activity concerned, or in the circumstances in which it takes place, that is detrimental. It also means that the process or activity must be worthwhile: it must meet environmental, social, and economic objectives.

To characterize an activity as sustainable, or to refer to sustainability, is by implication to predict the future. The concept of sustainability has, therefore, a degree of uncertainty attached to it. All we can do is follow actions that experience has shown to be sustainable and reject processes and activities that are clearly unsustainable. In addition, we must recognize that sustainable development incorporates the principles of equity and respect for other people. It therefore calls for patterns of consumption that do not preclude the enjoyment of acceptable standards of living by people in other countries.

Sustainable development is thus not limited to activities that affect the environment or result in economic growth. It is a complex mixture of activities — some with social, some with economic objectives; some based on conservation, some based on exploiting material resources, and some depending on intellectual resources — all aimed at enabling people to reach their full potential and enjoy life.

Ecological sustainability

Knowledge of whole ecosystems and of changes in the characteristics of the environment will lead to a better understanding of ecological sustainability and enable the design of policies and programs that aim to achieve sustainable development.

Life and ecosystems

Life is often equated to organisms alone, but there would be no life without air to breathe, water to drink, sun for warmth, and soils for plant growth (Rowe 1990). In fact, the things that people and other living creatures need in order to live are drawn from the ecosystems upon which they depend and of which they are a part.

Ecosystems are not only the source of all vital supplies but also the structures within which essential life-supporting processes take place. These include the regeneration of soil, the pollination of plants, and the global circulation of carbon, oxygen, and other elements necessary for life. If these processes are interrupted or impaired, the ability of the ecosystem to sustain people may be reduced. If the processes are severely impaired, the ecosystem will degrade or assume different, and perhaps less productive, characteristics.

Ecological footprints

It is possible to describe the extent to which plants and animals — particularly humans — depend on local and distant ecosystems. To do so is to describe the "ecological footprint." The footprint for a particular human population or economy is an estimate of the total area of land and water (ecosystems) needed to produce all the resources consumed and to assimilate the wastes discharged by that population or economy (Wackernagel and Rees 1996) (Box 1.3).

For most nations or communities, estimating the ecological footprint is far from simple. All the world's peoples depend in varying degrees upon global ecosystems. Trade facilitates this interaction in obvious ways. For example, the supermarkets of Canada and other high-income countries are filled with produce from all over the world. Oranges and grapefruits from California and Florida, dates from Morocco, jumbo shrimp from the waters of Malaysia, and roasts of lamb from New Zealand are displayed for sale from St. John's to Victoria. The flow is, of course, in both directions. Wheat from the Canadian prairies is used for bread in the United Kingdom; Canadian beef, cheese, apples, and other commodities load the shelves in Europe, Latin America, and the United States; and Canadian seafood products are shipped to Asia.

It is not only foodstuffs that are traded in the global market. Forest products and minerals, notably petroleum, and the articles and substances that are manufactured from those raw materials are also shipped worldwide. For example, petroleum and natural gas are exported from western Canada to the United States and imported into eastern Canada from the Persian Gulf states. In short, portions of most nations' ecological footprints are scattered all over the world (Box 1.4).

> **Box 1.4**
> **Connections to a global web — the international aluminum enterprise**
>
> *Aluminum is widely used in Canada and many other parts of the world. Use of aluminum instead of heavier metals in vehicles contributes to fuel efficiency. Food and beverage containers, cookware, aircraft parts, and household siding are some other common products derived from this versatile metal.*
>
> *Even a product as simple as a pop can is the result of an industrial process that stretches around the globe. The raw material, bauxite, is mined mainly in Brazil, West Africa, and Australia. Bauxite and its refinement, alumina, are then shipped to countries that have abundant electric power, such as Canada. In Canada, bauxite and alumina are further processed into aluminum in efficient smelters. Approximately 80% of the raw aluminum produced in Canada is then exported for fabrication in the United States, the Netherlands, Japan, South Korea, and many other countries around the world (Fig. 1.B1).*
>
> *This international trade in materials and goods is also an exchange in benefits and costs. Just as jobs and economic opportunities related to extraction, refinement, and manufacture are dispersed globally, so are the environmental impacts. Strip mining, for example, caused significant disturbance of Brazil's terrestrial ecosystems for many years. Refining may pose threats to aquatic ecosystems owing to the waste by-product — caustic red mud. The smelting portion of the process requires the intensive use of energy. If dams are built to produce low-cost hydroelectricity, landscapes and possibly lifestyles will change. Smelters emit sulphur dioxide, carbon monoxide, and fluorides, which affect vegetation and the quality of air and water.*
>
> *Corporations, with the assistance of environmental groups, have recognized these problems and made a commitment to fulfil environmental responsibilities. Progress is being made. In Canada, red mud is stored to minimize any threat to the environment, and smelters have significantly reduced their liquid wastes and air emissions.*
>
> *Like aluminum, most commodities are the result of extensive international movements of inputs and outputs. This trade is becoming increasingly significant, both economically and environmentally.*
>
> Source: Mendis (1994).

The export of hydroelectric power from a region or a nation is an example of a transaction that can have a substantial effect on ecosystems. This was the case in northeastern British Columbia, where the generation of power for the heavily populated southwestern corner of the province required the flooding of a large area and dramatically changed the ecological characteristics of the Peace River delta in northern Alberta; and in northern Quebec, where the flow from rivers into James Bay has been altered by the creation of reservoirs to generate power for export to the United States. There is relatively little international trade in water, but substantial flows have been diverted within countries — in the Prairie provinces, for instance, and in the southwestern United States.

Small communities in less developed countries rely less on trade and technology and leave a correspondingly smaller ecological footprint. Residents of these communities have to find most of what they need in their immediate surroundings and tend to live more in harmony with their environmental resources. Until only a few decades ago, this was the case for many communities in Canada's North.

Although it may be inconceivable to many people that their individual actions can affect the global environment, it is nonetheless true (Box 1.5). Ecological processes on local, regional, national, and global scales may be disrupted as a result of activities of individuals and communities. People's everyday actions have contributed to the destruction of stratospheric ozone, by emissions of chlorofluorocarbons (CFCs), and to global warming, by emissions of carbon dioxide. Local industrial processes and the lack of adequate regulation by local governments have also contributed to the overall problem. At a regional level, the acidification of lakes and streams and damage to trees in eastern Canada and New England are the result of emissions of sulphur and nitrogen oxides from coal burned in the U.S. Midwest.

The potability of groundwater and surface water from lakes and rivers and the suitability of fresh and coastal waters as habitats for invertebrate animals and fish can be severely impaired by pollution from untreated household waste and industrial discharges (see Chapter 10). Heavy metals, pesticides, and other highly toxic contaminants can be transmitted from sources thousands of kilometres away (see Chapter 13). Few of the major rivers in Canada or the rest of the world remain unpolluted throughout their lengths.

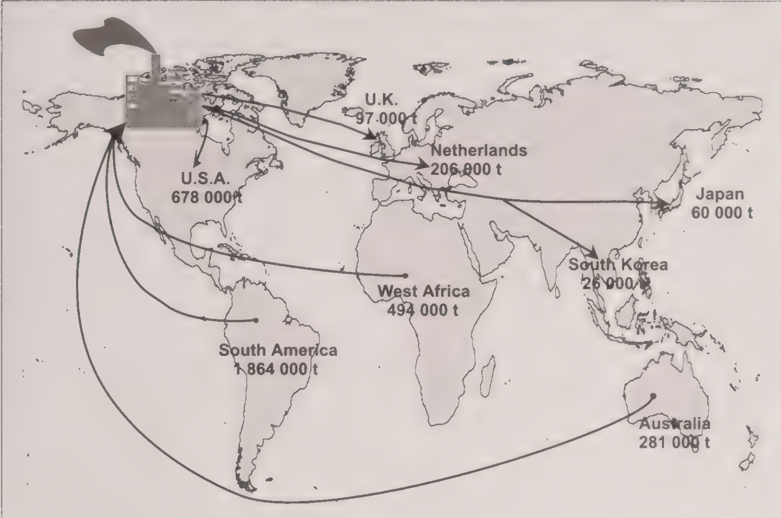
Determining an ecological footprint therefore brings into play ecological transactions among individuals, communities, and nations. These transactions encompass not only the exchange of goods and services in trade but also the ecological damages and benefits received from or exported to other places.

Ecosystem carrying capacity

Carrying capacity, simply stated, is the number of organisms that an ecosystem can support indefinitely (Box 1.6). A more sophisticated definition, from *Caring for the Earth* (IUCN et al. 1991), is "the capacity of an ecosystem to support healthy organisms while maintaining its productivity, adaptability, and capability for renewal." This expanded meaning reflects the significance of ecological processes and the importance of all ecosystem components.

Trying to define sustainable levels of human impact has led to much speculation about ecosystem carrying capacity for humans. Getting an accurate idea of carrying capacity is not easy. To supplement the

Figure 1.B1
Imports of bauxite and alumina into Canada and exports of aluminum from Canada, 1993



Note: Exports refer to unwrought, unalloyed aluminum only.

Source. State of the Environment Directorate, Environment Canada.

natural carrying capacity of particular ecosystems, the more wealthy nations can afford to pull in outside resources (e.g., fertilizers, fossil fuels, and water) for as long as sources exist. In poorer countries, ecosystem carrying capacity is restricted to natural limitations.

The question of carrying capacity underlies the widespread debate about whether there are natural limits to growth. Some observers claim that the global carrying capacity for people has already been exceeded. They believe that a continuing increase in human numbers and average consumption of resources cannot be accommodated and that growth in both population and consumption will need to be brought under control (Wackernagel and Rees 1996). If more equity among the world's peoples is a goal, a significant redistribution of goods and services — which can be attained only by a reduction of consumption in the high-income countries — will be required. In contrast, many people believe that technology and resource substitution offer countless possibilities for continuing growth, for cleaning up the environment, and for providing the raw materials upon which most economic activity is based.

In this debate, one thing at least is clear: the human species dominates the ecosphere like no other. It has been calculated that humans appropriate almost 40% of what all the land on Earth produces, and that proportion is growing in response to increases in both our numbers and rates of consumption (Vitousek et al. 1986). As well, human activity, primarily resource-related economic development, has caused widespread environmental deterioration, loss of species, and serious depletion of some resource stocks. As many of these changes to the ecosphere are irreversible, and as the economy depends upon the ecosphere, it follows that the current pattern of economic growth may be unsustainable.

The spur to growth is potent and persistent. Growth and development have resulted in social and economic benefits that are immense and quantifiable. The most obvious of these is the increase in average life span. Others include a dramatic reduction in the drudgery of work in the home, on the farm, and in the factory; better transportation and communication; and a tremendous increase in the quantity and variety of products that are readily available to consumers.

If we believe that these social and economic benefits are outweighed by the associated environmental costs, the conclusion that humans are living unsustainably is unassailable. Unfortunately, most environmental costs and benefits are difficult to measure, and there is no way to determine the balance quantitatively. This state of the environment report is, among other things, an attempt to more accurately determine the balance as a contribution to future decisions about the best course forward.

Social sustainability

Are there social constraints on development analogous to the ecological limits set by carrying capacity?

Social sustainability reflects the relationship between development and current social norms. An activity is socially sustainable if it conforms with social norms or does not stretch them beyond the community's tolerance for change. Social norms are based on religion, tradition, and custom; they are rooted in values attached to human health and well-being. The norms may or may not be codified in law. Some have to do with intangibles, such as deep-seated beliefs about right and wrong or values that are attached to the importance of different aspects of life and the environment. Even though they are intangible, these are very powerful factors.

Other social norms are less abstract: they concern language, education, family and interpersonal relations, hierarchies and class systems, work attitudes, tolerance, and all the other aspects of individual or group behaviour that are not primarily motivated by economic considerations. The main indicator of socially unsustainable development is antisocial behaviour, including damage to property, community disruption, and violence.

Most social norms are difficult to define and measure, and their limits are therefore hard to determine and evaluate. These dif-

ficulties are compounded in a multicultural country such as Canada because of the variety of communities with different social norms. In addition, social norms are not immutable, particularly in countries where change is pervasive. We live in a world of fast-moving social and economic change: behaviour that is unacceptable today may one day become fully acceptable, or vice versa. Social norms may persist in the short term, but most will almost certainly change in the longer term.

Nevertheless, the main consideration in assessing social sustainability is that, even though social norms may change, many are extremely persistent. Any proposal that would breach existing social limits will fail because the people involved will resist or oppose it. This leads to the question of how to deal with the social limits that must be respected to achieve sustainable development. It is clear that they cannot be measured. For instance, environmental features highly valued by some Canadian communities, such as a wild, free-flowing river, may seem worthless to an outsider. People who rely on traditional ways of making a living, particularly in occupations that are dependent upon a natural resource base, such as fishing, hunting, farming, mining, and logging, are often resistant to change to an extent that cannot be comprehended by others.

It may be concluded that social norms and social constraints on development must be taken into account in planning for sustainable development. To define social limits to sustainability, there is no alternative to exploring the issues in collaboration with the groups or communities concerned.

Economic sustainability

Economic sustainability, simply put, requires that economic benefits exceed or at least balance costs. It is more easily measurable than ecological or social sustainability, because its elements can usually be defined in money terms. However, it is at least as difficult to predict and is affected by as many variables.

Box 1.5
Global environmental cooperation

During the last several decades, people in Canada and other countries have become increasingly aware that our home really is "one Earth." This fact has two dimensions. The first is that the world's peoples have a common natural heritage, which all share and for which all must care. The second is that the damaging effects of environmental carelessness at any one location have impacts that ripple over great distances and time periods. Reflecting this growing awareness, the body of international environmental law and the commitment to coordinated action have developed far beyond what existed at the time of the first United Nations Conference on the Human Environment, held in Stockholm in 1972.

Global conventions aimed at conserving the world's natural heritage are of three types: those that protect populations of certain species by limiting the numbers that may be harvested, those that encourage the preservation of the habitats upon which valued species depend, and those that target reducing sources of pollution. Among the first type is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), promulgated in 1974. As well, there are some important regional conventions, including the grandparent of them all, the Migratory Birds Convention (1916), which had effect in Canada and the United States, and a number of conventions for the management of fish stocks caught by Canadian fishing fleets and those of other countries.

Conventions of the second type include the World Heritage Convention (1969), the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the Ramsar Convention; 1978), and the United Nations Framework Convention on Biological Diversity (1992). Canada is a signatory to all of these.

Canada contributes to meeting the objectives of these conventions by helping to draft and enforce the detailed harvest regulations by which conventions in the first group are implemented and by establishing protected or managed areas as called for by conventions in the second group. Canada also assists in these international efforts by contributing to funds created to help low-income countries meet their commitments to the conventions.

The first international conventions of the third type — those aimed at preventing damage from pollution — were motivated by concerns over specific regional problems. Notable among these was the Boundary Waters Treaty (1909) between Canada and the United States, which led to the Great Lakes Water Quality Agreement (1972). It was followed by a number of others intended to remedy situations associated with transboundary rivers in other parts of the world. The first global convention dealing with pollution was the International Convention for the Prevention of Pollution of the Sea by Oil (1954), which was adopted out of concern for the damaging effects of oil spills on seabirds. It was a relatively weak convention, but it led to the adoption of a series of stronger regional conventions, as well as the London Convention on the Dumping of Wastes at Sea (1972) and important elements of the Law of the Sea. The Law of the Sea, which came into force only in 1994, was in the process of negotiation for over 15 years. Other instruments of international law intended to control pollution include the Montreal Protocol on Substances that Deplete the Ozone Layer (1987), the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1989), and the United Nations Framework Convention on Climate Change (1992). All these conventions must be backed up by appropriate domestic laws and regulations if they are to be effective.

Box 1.6
"All for one, and then none for all"

The fundamentals concerning how to use resources in a sustainable manner have been discussed throughout history. In 1883, William Forster Lloyd, a British political economist, noted that a cattle grazing area could be used indefinitely as long as people did not try to graze too many cattle. Overgrazing would damage the pasture and reduce the number of animals that it could sustain.

Mr. Lloyd wrote that it was in the common interest of herders to control the total number of cattle. Nonetheless, herders continued to graze excess cattle to maximize personal gain. The result was that the number of cattle exceeded the carrying capacity of the pasture. Mr. Lloyd called this dominance of individual self-interest the "tragedy of the commons."

Economic sustainability is conditioned mainly by supply and demand: the availability and cost of inputs (primarily raw materials) and their transportation; the cost of extraction and/or processing, including energy, labour, and machinery; and the demand for the products (Munro 1994).

On the supply side, economic sustainability will increasingly depend upon using nonrenewable resources sparingly, as well as reducing the energy and material content per unit of production. As it is ecological factors that ultimately limit sustainability, economic development must use resources in ways that do not permanently damage the environment and must not impair the capacity of renewable resources to continually replenish their stocks.

On the demand side, consumption of threatened resources is continually putting sustainability at risk. Experience clearly shows that market forces, such as high prices, are not sufficient to safeguard overharvested stocks. In fact, high prices tend to spur on efforts to capture resources that have risen in value because of their scarcity. Where prices stay low (e.g., because of a more efficient harvesting technology), demand remains high and may reduce stocks below recovery levels. Thus, market prices, whether high or low, are not necessarily good indicators of economic sustainability.

Economic sustainability is threatened by anything that upsets a viable balance between benefits and costs. But determining that balance is a complex task. For example, mandatory emissions standards may require costly investment in more elaborate production processes. In many instances, however, adoption of such processes unexpectedly yields cost savings even greater than the added costs.

There is little need to emphasize the importance of economic sustainability; news reports refer to the health of the economy every day. Suffice it to say that economic sustainability is the basis upon which rest salaries, wages, pensions, and returns on investment — indeed, all systems for the distribution of income within a society. It follows, therefore, that any development activity that will not support continuing flows of income at levels that are socially acceptable will be economically unsustainable.

Monitoring Vital Signs

Sustainability depends upon many related factors, some little understood, most poorly defined, practically all difficult to predict. Is there any point, then, in trying to determine whether a policy, program, or project will be sustainable? There is, if the process is looked upon as an opportunity to benefit from experience. To be most valuable, progress towards sustainability must be recorded and reported on an ongoing basis.

Major development activities and policies should be monitored and evaluated. This is important for two reasons. The first is to provide a basis for deciding if policies should be adopted or activities continued without change, or if they should be modified or dropped. The second is to enable the identification or verification of indicators of ecosystem sustainability and to facilitate better decision-making with respect to comparable activities in future.

Monitoring makes a crucial contribution to understanding the functioning of ecosystems and trends both in the status of species and in the conditions of environmental components. Thus, it is not only the impacts of development that should be monitored; it is equally important to establish regular measurements of environmental, social, and economic parameters. This provides a background against which to compare the effects of changes brought about by development.

Across Canada, networks and programs already exist for gathering and reporting relevant sets of data on the environment and on human use of resources. Many of these data are drawn upon in the following chapters. Yet many are less useful than they could be, because they were not originally collected with sustainability goals in mind (Anderson et al. 1992). Other information relevant to sustainability but outside the purview of this report — for example, data pertaining to health, education, and culture — must be found elsewhere (Box 1.7).

Monitoring should be couched within a meaningful ecosystem framework. In other words, the existing networks that monitor environmental or socioeconomic parameters should be modified to reflect the goals of ecological sustainability. This means, first, integrating the network of sampling sites so that the factors that stress ecosystems may be linked more closely with their impacts; second, placing greater emphasis on assessing long-term and cumulative effects rather than short-term and isolated effects; and third, structuring the monitoring networks so that they provide information on the overall condition of ecosystems instead of just focusing on known problems in certain locations. Moreover, the criteria used in monitoring should be selected on the basis of their usefulness in answering questions related to sustainability.

Box 1.7
The precautionary principle

Throughout this state of the environment report, there is frequent mention of the lack of adequate data, especially trend data showing how conditions have changed over time. In many cases, data that are available are not concerned with what now appear to be the main environmental issues. This is because it is difficult to know what information will be needed until a specific problem has been defined. Problems identified in the last decade or so may require several decades of data collection before a general and quantitative picture is available.

Recognition of such shortages of relevant data has led to the development and increased acceptance of the "precautionary principle." This principle states that, where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. The principle was adopted by the countries — including Canada — that participated in the 1992 Earth Summit in Rio de Janeiro. The precautionary principle dictates that action should be taken to protect the environment if the "weight of evidence" suggests that such action is appropriate.

Achieving Sustainability

As important as monitoring is, it is not enough. The results of monitoring and evaluation activities must also be promptly interpreted and reported.

One key step is to develop a standard set of questions or protocols for assessing sustainability. The questions would relate to the expected environmental, social, and economic impacts of a proposed development activity or policy and would be asked as a matter of routine to ensure a careful and comprehensive decision-making process. Given political will, such a procedure would enhance sustainability and enable the avoidance of much that is unsustainable.

Defining sustainability may seem like a philosophical game, but it is much more than that. Canadians have developed a nation that is consistently ranked as one of the world's most desirable in which to live. Sustainability is a concept that provides a rational basis for thinking about and planning for the future, for working to ensure that we continue to have a desirable place to live, and for approaching uncertainty while minimizing risk. The notion of sustainable development as an achievable goal provides the only possible basis for a viable future for Canadians. More profits, jobs, and goods will be to no avail if they are gained at the cost of a compromised life support system.

Sustainability is a concept whose time has come. We must seize the challenge. The ideal may always elude us, but, as long as we continue to search, consult, and face up to hard choices, we will leave behind a better world for our children and our grandchildren.

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Chapter 2 The Way We Live

Highlights

Choices that individuals make every day — decisions about how we spend our time, where we live, and what we purchase — have a substantial cumulative environmental impact. At the same time, individual choices are limited by social and economic forces beyond our control.

■

Canadians, together with residents of other developed countries, represent only about 20% of the world's population but exploit about 80% of the world's resources. It has been estimated that if everyone on Earth lived as the average Canadian lives, two additional Earths would be required to provide all the resources needed and to assimilate the wastes discharged.

■

The quantity of goods considered necessary for a "decent standard of living" seems to spiral endlessly upward. Is it possible to maintain or improve our quality of life without an ever-growing consumption of energy and material resources? A large part of the answer rests on how we define "quality of life."

■

Single detached housing — with its heavy demands on energy and infrastructure — is as popular as ever. However, new houses are much more energy efficient than they were a decade ago, and well-designed higher-density housing is emerging as a viable alternative.

■

Many environmental issues underlie the rich supply of food we see in supermarkets, including intensive harvesting, land use, pesticide and fertilizer inputs, transportation, refrigeration, and packaging. By carefully selecting and preparing food items and managing food waste, we can help ensure that ecosystems will continue to supply our food.

■

In Canada, residential appliances account for about 13% of home energy use. As the energy to run most appliances costs more over the lifetime of the appliance than the appliance itself, choosing energy-efficient appliances can be cost-effective over the long term.

■

Many Canadians are not aware that common products around the home, such as household cleaners, pharmaceuticals, and paints, are hazardous to the environment if improperly used or disposed of. It has been estimated that a typical household produces about 6.8 kg of hazardous household waste each year.

■

There are roughly 14 million cars in Canada, and automobile use continues to rise each year. Although automobiles are a major cause of air pollution and use up a lot of land for roads and parking lots, lifestyle and technological changes both hold promise for reducing their environmental impact.

■

Encouraging sustainable consumption patterns and lifestyles requires the combined efforts of governments, consumers, and producers. Although new technologies that emphasize energy and material efficiency are expected to help reduce waste, energy use, and pollution, new attitudes and behaviours are required as well.

■

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> *"Good intentions and expressions of concern are not enough. Protecting the environment is the most serious challenge we face today. Every Canadian can and must get involved, not just today, but every day."*
>
> — Dr. Roberta Bondar (1994)

INTRODUCTION

Every day, Canadians participate in a variety of activities that make up what can be called the Canadian "lifestyle." Many Canadians remain unaware, however, that each of these activities carries with it an environmental implication of one sort or another. This chapter focuses on the types and severity of the environmental impacts associated with the decisions we make and the things we do as we go about our daily lives. It also emphasizes how we, as consumers, can make environmentally preferable choices that will limit these environmental impacts and allow us to continue to enjoy a good life — although we will need to be prepared to adapt to changes and to try new ways of living.

This chapter recognizes that the individual cannot be held solely responsible for a society's impact on the environment. The individual is a part of society; therefore, social, cultural, and economic influences inevitably shape our individual attitudes and behaviour. We are all part of a complex socioeconomic system with an associated range of technologies that we did not necessarily choose, and there are constraints on our choices in the form of what products, services, and infrastructure are available to us. On the other hand, we can choose to reinforce existing processes or we can encourage change. It is not a question of whether it is the system or individuals that have to adjust. Achieving environmental sustainability will require a combination of government, business, community, and individual initiatives.

The issues are not simple for individuals trying to make environmentally preferable choices. For example, a product or activity may be environmentally benign in itself but rely on production or distribution activities that have serious environmental consequences. It is hard to tell how bad for the environment a given choice is. While certain practices provide clear and immediate advantages for the individual, the disadvantages of resource-intensive and environmentally harmful practices are often not obvious, are more long term, and are far removed. For example, many commuters hop into the car rather than face the inconvenience of waiting for the bus. The benefits of driving to work are immediate and individual, whereas the environmental costs are more diffuse, borne by society generally, and even hidden — for example, in the form of diseases related to air pollution. Although each individual action seems inconsequential, we are beginning to see that serious cumulative damage to the environment results if many individuals choose those activities that have the most negative impact.

It has been estimated that if everyone on Earth lived as the average Canadian lives, two additional Earths would be required to provide all the resources needed and to assimilate the wastes discharged (Wackernagel 1994). While this type of estimate is not indisputable, it seems reasonable to assume that humanity is treading close to the limits of the ecosphere's carrying capacity. The global nature of the problem is even more pressing when we consider the lack of basic necessities for many people, especially in developing countries. Canadians, together with residents of other developed countries, represent only about 20% of the world's population but exploit about 80% of the world's resources (United Nations Development Programme 1994). Future global environmental sustainability will depend on reducing environmental demands per person in the developed world and improving living standards in the developing world in a way that maintains healthy ecosystems.

As an "ecosystem approach" to ecological change becomes more prominent, individuals are recognizing that human, social, and economic systems are constantly interacting with other physical and biological parts of the ecosystem. All activities from the individual to the institutional level are interconnected and linked to the health of the ecosphere (Fig. 2.1). The demand on resources that we make as individuals has implications for the long-term supply of clean air and water, fertile soil, and genetic diversity — in general, the conditions for healthy living.

The quality of life for Canadians

Canadians, in general, enjoy a high quality of life, as measured on a variety of social and economic scales. Gross domestic product (GDP) is one measure of a country's ability to generate wealth. Canada's GDP exceeds $20 000 per person per year, almost equal to that of the United States and higher than that of Australia and the Netherlands.

However, economic measures alone do not adequately reflect human well-being. Attempts to measure quality of life include the United Nations' Human Development Index. The index is based on three indicators: life expectancy, knowledge (derived from adult literacy and mean years of schooling), and standard of living (the per capita gross national product adjusted for

Figure 2.1
Taking care of the ecosphere

Source: Friends of the Earth.

Figure 2.2

Per capita urban solid waste production, energy use, water use, and GDP, 1991

Note: Waste figures for Canada refer to residential waste. Comparisons are difficult, as waste is defined and measured differently between countries GDP values are from 1990

Source: Statistics Canada (1994b)

the local cost of living). Canada ranks number one among all countries of the world according to this measure, with a Human Development Index value of 0.932 on a scale that runs from 0 to 1 (United Nations Development Programme 1994).

Another measure of quality of life is the Physical Quality of Life Index, prepared by the Washington, D.C.-based Overseas Development Council. This index also focuses on three measures: child mortality, literacy, and life expectancy. Canada does not rank quite as high with this index — 10th out of 170 countries (Kurian 1994).

These various measures of the quality of life do not take the sustainability of the environment into account. What kinds of environmental stresses are involved in maintaining the high quality of life that many of us enjoy in Canada? Is that quality of life sustainable? These questions are difficult to answer, but we can get a feel for where we stand if we look at some common parameters.

Canadians use energy and water and generate household garbage at rates similar to those of residents of other developed countries (Fig. 2.2). The people of Sweden, with a higher GDP per capita, use less water and produce less waste. The people of Japan, with a slightly higher GDP per capita, use much less energy. Some of the reasons for high per capita energy use in Canada are the country's cold climate, the long distances between population centres, and energy-intensive industries that export products to countries like Japan. Nevertheless, lifestyle factors are also important. As Figure 2.3 shows, almost 20% of energy consumption in Canada is residential. Moreover, large portions of the balance (transportation, industrial, commercial) are closely connected to Canadian lifestyles. Passenger transportation and residential activities together account for one-quarter of carbon dioxide emissions in Canada (Fig. 2.4).

Adopting more environmentally sustainable lifestyles should not require a reduction in the quality of life. For instance, Figure 2.5 shows that energy consumption per capita has not increased and that energy consumption per dollar of GDP has been decreasing since the early 1970s — evidence that it is possible to do more with less. Garbage production is another area in which progress is being made. Recent studies show that waste recovery rates by recycling and composting almost doubled for municipal solid waste between 1988 and 1992 (see Chapter 12). This shows that total waste can be reduced with minimal changes to our everyday habits.

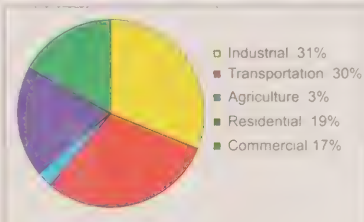
A high quality of life with reduced waste, energy use, and pollution is the challenge we need to meet in order to achieve environmental sustainability. New technologies that improve the resource and energy efficiencies of our activities will be very helpful. But new attitudes are needed as well, to promote choices that are less stressful on the environment. In other words, we also need to examine more closely what constitutes a high quality of life, considering environmental factors as well as material and health ones.

How We Spend Our Time

The way we use our time affects the impact we have on the environment. Figure 2.6 shows how adult Canadians spend their time. These averages for the entire population make it clear that a lot of people spend large amounts of time in the workplace and getting to and from work. For many, time itself has become a scarce resource. Juggling the competing demands of work and home has led to the increased use of private automobiles and a growing reliance on labour-saving but energy-intensive household appliances.

Figure 2.3

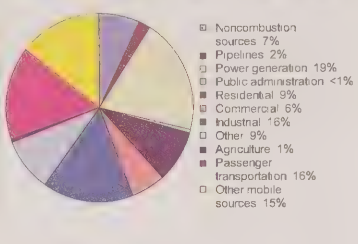
Energy consumption by sector, 1994



Source: Statistics Canada (1994d)

Figure 2.4

Carbon dioxide emissions by sector, 1993

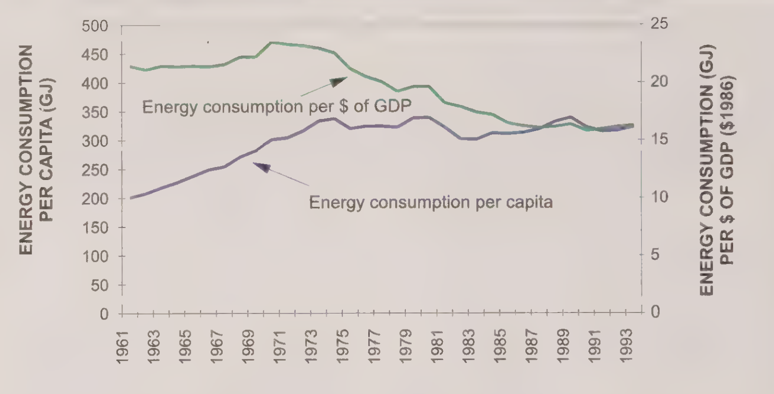


Note: Percentages do not total to 100 owing to rounding.

Source: Environment Canada (1995b).

Figure 2.5

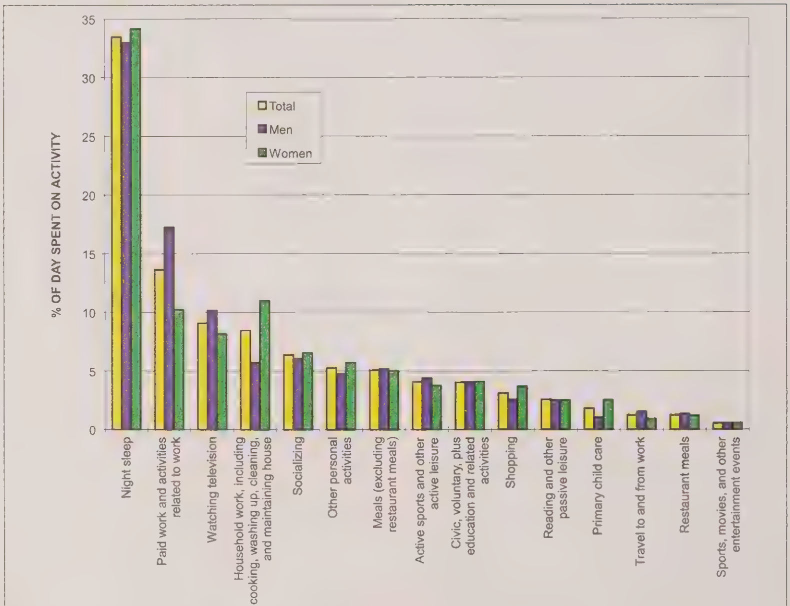
Selected energy indicators, Canada, 1961–1993



Source: Adapted from Statistics Canada (1994a); Environment Canada (1995e).

Figure 2.6

Average time spent on daily activities, 1992



Note: Time spent on daily activities is averaged over a seven-day week and over the entire population aged 15 and over.

Source: Adapted from Statistics Canada (1994c).

Work and the environment

From the part-time wage earner to the top company executive, from the home workplace to corporate head office, every job has environmental implications. The workplace may contribute to environmental degradation in obvious ways — for example, through the use or release of toxic substances. However, some workplace contributions are less obvious — for instance, the use of water, energy, paper, and other products, contributing to overall consumption. Many of these environmental impacts can be substantially decreased without reducing the economic benefits of the workplace activity. Indeed, in many instances, reduced consumption of resources and products means lower costs and results in both environmental and economic benefits.

Employees have an impact on the success of workplace environmental initiatives as individuals, as members of union committees, or as progressive managers. Employees have helped achieve policies in such areas as "greener" purchasing, environmental codes of practice, nonsmoking buildings, and conservation strategies for waste, water, and energy (see Box 2.1). Employees often initiate environmental programs on their own, with some company support. Workplace programs that promote activities such as bicycle commuting and tree planting are enjoyable ways of sharing information and can be instrumental in achieving some fundamental shifts in attitudes.

In fact, the workplace is a good place for raising awareness, because structures for training and education (e.g., health and safety committees, programs to upgrade skills of workers) are often already in place.

For example, the Canadian Labour Congress, as a follow-up to its "Greening the Workplace Union Environmental Education Project," is revising its health and safety courses to include a strong environmental

perspective and is developing a practical training course on workplace environmental action. Environmental committees with employee members can influence other employees to participate in such initiatives as office recycling programs. Such committees are also a channel between staff and management through which to exchange ideas on introducing new programs or improving existing ones.

If the work environment includes supportive structures, individual initiatives are easier to mount. When these supports are not in place, it can be very difficult for employees to heighten their awareness of the environmental implications of their work, to encourage corporate responsibility, or to act on their concerns, especially if their job may be at risk.

One trend that is generally seen as positive for the environment is "telework" or "telecommuting." Some corporations are offering employees the opportunity for work-at-home arrangements that make use of computer and telecommunication technologies. The main environmental benefit is a reduction of air emissions and other environmental stresses due to commuting. Also, because employees are in the office less, telework can allow for more shared office space, reducing real estate requirements and associated heating and cooling costs.

Box 2.1
Saving paper in the workplace

Although it was predicted that computers would lead to the paperless office, paper use has actually increased in 50% of companies in Canada owing to computers, according to a Pitney Bowes survey conducted in 1994. Employees use more paper by printing more drafts. However, many companies and employees are now participating in efforts to reduce paper use and recycle used paper (Table 2.B1).

Table 2.B1
Participation in activities to reduce paper waste, 1994

Waste reduction activity	% of respondents participating
Recycle paper	83
Two-sided photocopying	60
Use of back of paper	56
Revision of document on computer rather than printing new hard copy	55

Source: Pitney Bowes (1994).

Leisure and the environment

The way we use our leisure time can also have an impact on the environment, although assessing all the environmental implications of leisure activities can be complicated. For example, many outdoor sports that may seem very environmentally friendly require considerable outfitting in sports clothing and equipment and use resources such as land for ski areas or golf courses. Other examples of environmental impacts associated with recreation include the chlorofluorocarbons (CFCs) often used in the refrigeration systems of indoor skating rinks, the chemicals used to purify the water in swimming pools, the emissions and spills from powered equipment such as snowmobiles, and the cars used to drive to the cottage or to an event. Even such low-impact activities as camping and hiking can harm the environment, especially in sensitive areas. While recreational pursuits are important components of health and quality of life, effective education can help to ensure that more people "tread softly on the land" when participating in their favourite activities.

Estimates of energy use, material use, emissions, and waste can be used to gauge whether particular activities are environmentally sustainable. Generally speaking, fuel-dependent activities (e.g., snowmobiling, motorcycling) are more harmful to the environment than human-powered activities (e.g., hiking, skiing). In certain fields, fuel-dependent activities tend to predominate. For instance, in the area of pleasure boating, there are more than five times as many motor boats and yachts as sailboats in Canada (see Box 2.2). Power boating, however, has a deleterious effect on the environment whenever it is done, causing noise, air, and water pollution. Controlling the use of such equipment is an effective way to minimize damage when environmental impact is a concern.

Human-powered activities, on the other hand, tend to have less impact than fuel-dependent activities, especially if individuals follow environment-friendly practices when pursuing them. If hikers stay on designated trails and do not litter, for example, they can enjoy the outdoors without causing much damage to it. The cumulative impact of human-powered activities on the environment is, however, potentially significant, because of the huge numbers of Canadians engaged in them. About 20% of all Canadians participate in each of skating, downhill skiing, jogging (or running), and golf. About 2.4 million Canadians participated in amateur sport at the competitive level in 1988, and over 3 million took part in physical activities that were directed or coached. Participation in spectator sports and sports clubs has also increased (Gauthier and Haman 1992).

Many cultural and recreational activities — such as going to the local theatre, museum, or concert; or walking, gardening, swimming, or bicycling — can be highly sustainable. Such activities are low in cost, easy to schedule, and close to home, and they require little supervision or training. For example, home gardening provides good exercise and is reasonably sustainable if done with little or no use of pesticides, power equipment, or overpackaged products. Bicycling and walking are excellent exercise in themselves and can also reduce automobile use.

Canadians are also using their leisure time to actively help the environment. Across the country, communities — often in cooperation with environmental groups — have started programs that organize people to pick up litter along streams, plant trees, watch for vandalism in natural areas, lead naturalist walks, take part in "no car" days, and participate in many other pro-environment activities. Each year, individuals are honoured with environmental awards given by various levels of government, nonprofit groups, and private organizations.

Leisure time enhances the quality of life. By choosing less environmentally damaging activities and by carrying out our leisure activities in a way that reduces their environmental impact, Canadians can go a long way towards reducing the long-term environmental impact of leisure activities in Canada.

Box 2.2
Power boats versus sailboats

Motor boating is one leisure activity that is receiving attention because of its environmental impact. The exact number of recreational pleasure crafts is not known, but estimates are shown in Table 2.B2.

Estimates of the contribution of pleasure crafts to pollution are still preliminary. Sailboats have relatively little direct polluting effect (except for their need for antifouling paint), but the impact of motor boats can be substantial. Consider the following:

- *A typical 17-foot (5.2 m) runabout needs about 25–30 L of fuel an hour. Average fuel consumption is about 1–2 km/L compared with an average of well over 8 km/L for automobiles.*
- *Some estimates are that as much as 25% of total hydrocarbon fuel and lubricating oil goes out the tailpipe. For example, pleasure boats in the heavily populated Quebec–Windsor corridor may contribute as much as 8% of the total hydrocarbon emissions in the corridor. Air pollution may be as much as 25–30% higher than the estimate because of engines that have deteriorated through ageing or have been improperly maintained.*
- *Boat use in certain areas exacerbates existing pollution problems. For example, pleasure boats in the St. Lawrence River combine with the impacts of marine shipping and the nearness to land to further increase urban air and water pollution problems.*
- *Powerful wakes disturb aquatic life, endanger people swimming or canoeing, and erode vulnerable shorelines.*

Table 2.B2
Fuel consumption by recreational pleasure crafts

Type of vessel	Estimated no. of vessels	Fuel consumed per vessel (L)	Total fuel consumed (L, millions)	
			Diesel	Gasoline
Sailboats	124 000	80.7	3.6	6.4
Motor boats and yachts	693 500	1373.9	77.8	875.0

Note: Does not include private ocean-going vessels.
Source: Yumlu (1994).

THE HOMES WE LIVE IN

Generally speaking, Canadians are among the best-housed people in the world. According to the World Health Organization, over 100 million people worldwide have no shelter at all, and around 1 billion lack adequate shelter — and this is expected to double by the year 2000 (WHO 1988). On average, Canadian houses are larger than those in many other countries. This means that Canadian homes may require more energy and resources per person accommodated than do homes built to similar standards elsewhere.

The type, size, and location of our homes affect the community as a whole and leave a big imprint on the ecosystem. The design and construction of our homes influence efficiency of land use, energy and water consumption, the need for upkeep in such areas as painting, and maintenance of a healthy indoor environment. Landscaping influences efficiency of water use and availability of habitat for birds and other wildlife. The type of housing, development standards, and residential densities have a major impact on the cost of providing and maintaining operating infrastructure such as paved roads, sewers, and water supplies, as well as on the costs of providing public services such as recreational facilities and public transit.

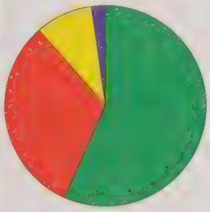
Canadian housing aspirations and household structure

Our housing choices are driven by questions of affordability, location, space, amenities, and aesthetics. Research shows that, for many of us, the single-family house remains the dwelling of choice. In 1992, 57% of Canadians were living in single detached homes, and 32% lived in apartments (Fig. 2.7). A recent survey of young Canadian families in Montreal, Toronto, and Vancouver showed that, whereas 48% were living in single detached housing, 80% would prefer to live in this type of dwelling (CMHC 1993).

Public opinion research (Fig. 2.8) shows that most Canadians aspire to live in the suburbs, closely followed by those who wish to live in a rural setting or a small town within 160 km of an urban centre (Gregg and Posner 1990).

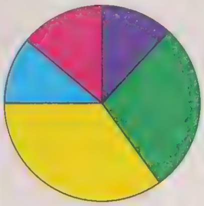
Along with social expectations, changing demographics have a major impact on housing markets and hence on the environmental impact of shelter. Households are getting smaller. In 1961, the average household size was 3.9 persons, and less

Figure 2.7
Distribution of Canadian households by dwelling structure, 1992



Source Statistics Canada (1994a)

Figure 2.8
Where Canadians prefer to live



Source: Gregg and Posner (1990).

than 10% of all private households consisted of just 1 person. In 1991, the average household size was 2.7 persons, and over 2.3 million people lived alone — about 23% of all private households. This trend may be slowing down, however; since 1989, the growth of housing has slowed relative to population growth (Statistics Canada 1992).

Environmental implications

The low-density pattern of development that usually surrounds single-family dwellings results in large distances between homes and schools, shopping centres, community facilities, and workplaces. Transportation alternatives to the private automobile, such as walking, bicycling, and public transit, become unappealing, inefficient options. An environmental review in the Regional Municipality of Ottawa–Carleton showed that a neighbourhood's physical structure has an effect on how much people use alternatives to the car. Compared with residents of older neighbourhoods in the centre of Ottawa, residents of suburban Kanata on average drove twice as much and walked and cycled one-third as much (Richards 1995).

Our preference for detached housing has other environmental implications. For instance, detached houses require more energy for heating and cooling than does multiple housing (see Table 2.1, for example). They also cost more in infrastructure services and community facilities. Depending on the size of the house and the subdivision plan used, a single detached house can require as much as four times more infrastructure per unit than does duplex housing (D'Amour 1993). Spread-out neighbourhoods also mean that municipal services such as snow and garbage removal, school buses, and public transit (see also Chapter 12) need to cover a larger area.

Opportunities for reducing the environmental impact of housing

Many of the needs met by single detached houses, such as the need for privacy, could also be met by well-designed higher-density housing. New alternatives to conventional suburban designs incorporate some of the features of older city neighbourhoods and traditional villages: a more compact urban form, narrower streets, higher residential densities, and a higher mix of land uses. These features help reduce dependence on the automobile and facilitate travel by foot, bicycle, and public transit.

Multiple housing, such as semidetached units, reduces both the amount of material required for construction and the environmental effects of home occupancy. Many of the world's finest cities combine a comfortable living environment with efficient use of land. According to one study, Montreal North has the highest population density in Canada; in 1991, the municipality housed 7 753 persons per square kilometre (Statistics Canada 1992). Yet Paris had a housing density more than three times that of Montreal. And both Montreal and Vancouver have housing densities considerably greater than Toronto's (Kurian 1994).

Making more efficient use of the existing housing stock, by sharing homes or creating accessory apartments, is one of the steps that can be taken to reduce the impact of our housing choices on the environment. Indeed, there are signs that Canadians are beginning to move away from the "bigger is better" attitude towards housing. "There is considerable interest in smaller homes that provide a high-quality environment, convenience, and security" (Energy Pathways 1991).

Energy consumption is another area in which progress is being made. Builders, purchasers, and occupants of existing housing are beginning to make substantial environmental improvements, often because it is cost-effective. For example, according to Canada Mortgage and Housing Corporation (CMHC), per household energy consumption dropped some 32.5% between 1973 and 1987. Over half of this

Table 2.1
Energy efficiency of alternative housing types

Type of unit[a]	Space heating requirements (BTUs, millions)	Energy savings (%)
One-storey single-family detached home	64	Base
Two-storey single-family detached home	59	15
Two-storey duplex	45	30
Two-storey triplex	42	35
Low-rise apartment, same space as above units	38	40
Low-rise apartment, less space than above units	21	67

[a] All the units are three-bedroom units except for the last unit, which is a two-bedroom apartment

Source: D'Amour (1993)

decline was due to improvement in the energy efficiency of new housing combined with reinsulation of older homes (D'Amour 1993).

A typical house in Canada uses roughly 50 000 kWh of electricity each year; a new design known as the "Advanced House" uses only 7 500 kWh per year. New houses built to Canada's R-2000 energy efficiency standard cost about 2–5% more than conventional new houses, but heating and cooling costs can be up to 50% lower per year depending on the type of housing and regional climate (D. Chamberland, CMHC, personal communication). By 1992, 12 years after the introduction of the R-2000 house, only 6 000 had been built, even though 125 000–200 000 new houses are built in Canada each year on average (Lougheed 1992). Nevertheless, as a result of the research that goes into such programs, new houses are better built and much more energy efficient than they were a decade ago (see Box 2.3).

With passive solar design and thermal efficiency, the sun can supply as much as 25–40% of a building's energy requirements (D'Amour 1993). Situating the home to take advantage of the local topography and landscape can also reduce energy needs. For example, new homes may be oriented to pick up cross-ventilation for summer cooling. Deciduous trees provide shade in summer, and coniferous trees provide shelter from the wind in winter.

As the Canadian housing stock grows at a rate of approximately 2% a year, it will take a long time to replace the current stock with new homes that are more energy efficient. In existing homes, effective insulation can significantly reduce energy consumption. Of the 5.8 million single detached houses in Canada in 1993, 31% of those with basements had uninsulated basement walls, 26% had air leaks in at least one exterior wall, 10% had at least one single-pane window without a storm window, and 21% had air leaks near windows (Natural Resources Canada 1994a). In addition to better insulation, switching to a more efficient heating system will also reduce net energy consumption (Statistics Canada 1994b).

Box 2.3
Healthy housing

Two demonstration projects have been undertaken as part of Canada Mortgage and Housing Corporation's (CMHC) Healthy Housing initiative.

The Toronto Healthy House, under construction in 1995, is a three-bedroom infill home that is completely self-sufficient. It harvests its own energy, collects rainfall and purifies it for drinking, and biologically treats its own waste. As a result, the house does not need to be connected to municipal services. Because of its low operating costs, the house meets another important criterion: affordability. The annual water consumption cost is zero, and space heating requirements are less than a quarter of those for an average home.

The Red Deer Project '94, sponsored by CMHC, Natural Resources Canada, and the Canadian Home Builders' Association, demonstrated how Healthy Housing principles can also be applied to existing housing. The aim of the renovations to a 1905 home was to demonstrate environmental responsibility through material selection; energy efficiency through increased insulation, air tightness, and equipment selection; and healthy housing through ventilation and careful attention to material selection and moisture control. For example, materials that could be salvaged in any demolition were reused, old windows were replaced with new energy-efficient models, and larger windows were installed on the south-facing walls for solar gain and natural light.

Source: D. Chamberland, CMHC, personal communication.

Other opportunities to lessen the environmental impact of housing include planning for better use of land and transit and infrastructure systems, choosing more benign housing materials, and recycling and reusing waste construction materials.

Although consumers could do more to influence the growth of environmentally efficient housing and retrofitting, there are some important constraints. Availability and choice are limited. The energy and cost savings that accrue over time are offset by an initial capital cost that puts many people off. Almost half of respondents to a recent survey considered R-2000 homes too expensive. While understanding that it is important to have energy-saving features such as upgraded heating systems, automatic thermostats, and high-efficiency appliances and lighting, most Canadians expect energy-saving investments to pay for themselves within a relatively short time frame (i.e., three years) (CMHC 1995). Finally, some consumers are not aware that more environmentally benign options are available. Only 45% of Canadians in the above-mentioned survey had heard of R-2000 homes (CMHC 1995). Special fiscal arrangements and public education for consumers and builders may help to erase some of these barriers.

The higher the environmental efficiency of the ways we find to satisfy the aspirations of Canadians for safe, comfortable housing that allows for privacy and access to amenities, the more environmentally sustainable our housing will be. Lessons in technology and planning could then be transferred to other countries, and the environmental benefits would be multiplied at a global level.

The Food We Eat

Although food production in Canada has been increasing at a faster rate than the population, this is not the case everywhere. Disasters such as droughts and floods as well as environmental problems such as loss or degradation of soil caused by human activity expose the vulnerability of the world's food supply. In their search for food, desperate populations in developing countries degrade the environment and repeat a continuous cycle of hunger and poverty. Forests are cleared to grow crops, the soil erodes, and yet more forest must

be cleared. Recent Food and Agriculture Organization statistics show a decrease in world food security owing to a drop in global output and drawdown of stocks (FAO 1994).

In Canada, food is plentiful for most people. Certainly in terms of caloric intake, average Canadians are among the best-fed people in the world (Kurian 1994). In addition, Canada has one of the lowest expenditures on food as a proportion of total household spending. The average Canadian family spends 11% of total household spending on food. In contrast, U.S. families spend 12%; many European countries are in the 12–17% range; and others are much higher still. In many developing countries, more than 50% of household spending is on food (World Resources Institute 1994). According to one survey, the cost of food relative to average wages is very low in Canada (Fig. 2.9).

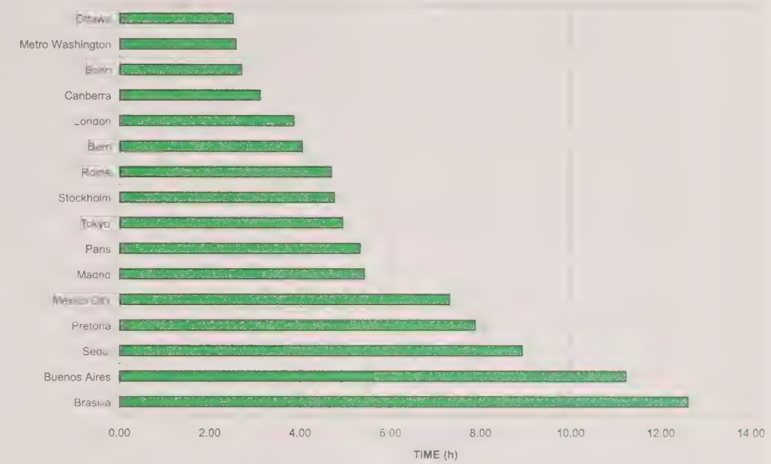
Many Canadians living in urban areas rarely think about where their food comes from. There seems to be a continuous and bountiful supply of a wide variety of food. There are, however, many environmental issues behind the rich supply of food we see in supermarkets.

Production, processing, and distribution

In some ways, our food choices are becoming more limited. Some sources of food are already heavily stressed through intensive harvesting or pollution (for example, see Box 2.4). Also, the diversity of food varieties is shrinking. Worldwide, fewer than 100 species provide most of the world's food supply out of the thousands of species and many more thousands of varieties (subspecies) that have been grown since the development of agriculture 12 000 years ago (World Resources Institute 1992). Too little genetic variety increases the risk of extinction. Sudden changes in circumstances may kill off species not suited to the changed conditions (see also Chapter 14).

On the other hand, improvements in agricultural practices are cause for optimism. New hybrid varieties are constantly being developed through crop breeding efforts that emphasize disease and pest resistance

Figure 2.9
Time spent to earn the retail value of a given basket of food in 16 capital cities



Source: Traub (1994)

Box 2.4
Disappearing meals

Of the 90 million tonnes of fish eaten by human beings each year, cod from the Grand Banks supplied some 800 000 t, or a little less than 1%, in the 1970s (Brown et al. 1993). The loss of the Atlantic Cod fishery means a loss of 6.5 billion servings of fish, or more than 237 servings for every Canadian every year (Department of Fisheries and Oceans 1989).

The loss of the Atlantic Cod can be made up with fish from other oceans. However, fish stocks around the world may be threatened. Ocean life is exposed to chemicals from spills, coastal land pollution, and deliberate dumping of hazardous and other wastes. Some marine resources are being overexploited through the use of technologies that outstrip the system's ability to replenish itself. Factory ships and driftnets increase the yield but also increase the waste of resources. As the fish disappear, so do the livelihoods of the people whose jobs depend on their harvesting, processing, and transportation.

as well as nutritional quality. This should result in healthier crops requiring fewer inputs of pesticides. There is some evidence that pesticide use in Canada is decreasing somewhat and that appropriate farming practices have reduced the risk of soil erosion in Canada (see Chapter 11).

Concerns remain, however, as to whether Canada's resource-intensive food production system is truly sustainable. Extensive mechanization and high fertilizer and pesticide inputs mean high yields. Some argue that because more crops can be produced on a given area of land, more land can be left as habitat for wildlife or other ecosystem functions. Others argue that the impacts of the extensive use of fossil fuels need to be considered, that there may still be cumulative ecosystem and human health impacts from pesticide use, and that large monoculture operations are susceptible to major environmental stresses such as climate change and stratospheric ozone depletion.

A few producers have responded with "ecological agriculture" or "organic farming." Others are taking intermediate steps to establish a more sustainable food production system. Integrated pest management, soil conservation, recycling organic material, and multiple cropping are examples of changing farming practices. There are also some initiatives to maintain food resource biodiversity through the development of seed and gene banks, rare species livestock farms, and botanical gardens and the maintenance of natural wildlands.

Consumers can encourage the broadening of the genetic base by choosing a wide variety of food products. Those concerned about the environmental impacts of agriculture can favour products that are known to put less stress on ecosystems during production. But this is an area where the choices are complex. For instance, organically grown foods tend to be more expensive, and there is no consistent labelling of foods produced in ways that are more sustainable. At another level, consumers can try to encourage government policies that enhance genetic diversity, promote appropriate farming practices, and expand research into what constitutes a sustainable food production system.

A great deal of the food we eat in Canada is imported, and agricultural exports make a significant contribution to the Canadian economy. However, several development and environmental issues are associated with food trade. For example, a lot of fuel is burned to transport fresh food long distances. It has been estimated that it takes three times as much energy to truck a head of lettuce from California to Toronto as it does to grow it locally in season (adapted from Teitel 1992). Food prices tend not to fully incorporate the long-term environmental costs of production and transportation.

Food trade can assist developing countries in obtaining foreign currency to purchase tools and materials not available locally. However, the economic lure of supplying a foreign market such as Canada can lead to large single-crop export operations, crowding out traditional foods, reducing the healthfulness of the local diet, and decreasing biodiversity (Teitel 1992). An alternative approach is highlighted by Cultural Survival, Oxfam, and other "trade not aid" groups, which, assisted by Canadian contributions, are supporting sustainable agricultural practices through small community projects in developing countries. These groups trade in food products grown under improved conditions that benefit not only the environment but also the people.

There are also health aspects to our reliance on imported foods. In many developing countries, levels of pesticide use are much higher than in Canada. Health effects related to processing and food content are another cause for concern for many consumers. In a 1993 survey, 6 out of 10 respondents expressed concern about additives and preservatives (Grocery Products Manufacturers of Canada 1993). There is some documented basis for these concerns. For example, the number of anaphylactic (severe allergic) reactions to food is increasing each year. The reason for this increase is unknown; however, one study has implicated the widespread use of protein additives in commercially prepared food (Canadian Paediatric Society 1994).

Packaging is another component of our reliance on processed food. Packaging consumes materials such as glass, metals, cardboard, and plastic, uses energy in production and transportation, and ends up in landfill if not recycled. A lot of material goes into food packaging, such as films, trays, and containers. Yet some packaging is often essential to protect the product, preserve freshness, and prevent tampering. Without packaging, much more of the product itself would go to waste. In Canada, packaging, preservatives, date labelling, and other processing and handling techniques ensure that only 2% of food is wasted before reaching the consumer. In developing countries, roughly 30% of food goes to waste (Adams et al. 1991).

Waste minimization programs are helping to reduce or eliminate unnecessary packaging. Some grocery store, processor, and restaurant waste management systems include recycling of both shipping containers and miscellaneous materials such as polystyrene coffee cups. The National Packaging Protocol, coordinated by the Canadian Council of Ministers of the Environment, aims at a 50% reduction of 1988 levels of packaging waste by the year 2000. This will require that processors and retailers minimize packaging further, utilize more recyclable packaging, and introduce packaging recycling at the plant level.

One way of cutting down on packaging needs is by using more fresh food in season. Frozen food requires 10 times more energy for storage than does fresh food (Durning 1992). However, the environmental benefits are by no means all one way. Commercially prepared food may be processed more efficiently, with less spoilage, waste, and energy use than home-processed food. Also, when fresh food is not in season, it must be transported over long distances, and the energy used may be comparable to that used to process frozen food (see Box 2.5).

At the retail level, grocery stores can achieve both cost and environmental savings with innovative techniques. Some processors and restaurants have converted to natural gas or propane for cookers, ovens, and heating, thereby helping to reduce air pollution. Modern lighting technology ensures good product illumination while conserving energy.

Shopping, cooking, and cleaning up

Purchase of produce in season is an important component of sustainable food shopping. In the winter, easily stored vegetables such as carrots, cabbages, and potatoes are inexpensive and plentiful, and their purchase supports local farmers. Some communities have developed innovative arrangements for linking consumers and farmers. For instance, at the Harvest Share Co-op near Fredericton, the customer agrees to purchase a share of the harvest from the farmer: the farmer has a guaranteed market for the food being grown, and the economic risks of farming are shared with the community. Local biodiversity in-

Box 2.5
Refrigeration: environmental costs and benefits

Refrigeration of food illustrates the complexity of decision-making with respect to the use of technology that has environmental impacts. Freezers use high levels of energy, often employ stratospheric ozone-depleting CFCs or toxic ammonia gas, consume water for cooling (on a commercial scale), and are difficult to recycle at the end of their useful life. On the other hand, freezing reduces food spoilage and wastage, and the incidence of food-borne disease is reduced. Although frozen food must be transported in refrigerated trucks and stored in home freezer units, locally grown frozen food can be consumed in the winter, reducing the need to truck fresh food in from warmer areas. And if food is in the freezer at home, there may be no need for a trip to the store, so storage of frozen food can contribute to energy savings and reduce air pollution.

There are ways to reduce the environmental impact of almost every technology, including refrigerators and freezers. Although many Canadian grocery stores still have energy-wasting open freezers, high energy costs in Europe mean that most stores have freezer shields or doors on freezers to reduce energy consumption. Thermal glass panes, heat converters, and advanced temperature controls on freezers and refrigerators help achieve energy efficiency. Changes to piping systems and special adaptors can reduce refrigerant use by one-third or more (Pocock 1993).

At home, many older houses have pantries, pits, root cellars, or cool areas for food storage. Natural ventilation in cool seasons provides free cooling for grains, oils, beans, root vegetables, beverages, and canned goods. A refrigerator positioned next to a stove has to consume more energy because of the additional heat. Buying the right size of refrigerator is also important: if it is too small, the family will have to make more trips to the store; if it is too large, it will waste energy.

Good food preparation practices reduce the energy used in refrigeration. Ways to reduce energy include:

- *thawing frozen food in the refrigerator and letting warm food cool before storing;*
- *filling but not overcrowding the freezer and refrigerator; and*
- *avoiding opening the refrigerator unnecessarily. Some 2–4% of refrigerator energy is lost every day by people looking inside "for inspiration."*

To reduce the release of ozone-depleting CFCs, householders can:

- *ensure the CFCs are recovered when disposing of a refrigerator;*
- *buy a new refrigerator that uses HFC-134a as a coolant (until a better alternative is found);*
- *ensure that the service person does not vent the CFCs;*
- *demand CFC-free refrigerators (now on the market in Europe); and*
- *patronize dealers who recover and recycle CFCs when maintaining appliances.*

Disposal of domestic refrigerators is a major problem. The average home refrigerator contains at least 180 kg of steel, 0.25 kg of CFC-12 refrigerant, and 1 kg of CFC-11 blowing agent, as well as a variety of plastics (Leaversuch 1990). Disassembly is currently very costly; future redesign to permit easy disassembly is being considered.

creases as more species are selected to improve variety for participants. Several provinces also have programs to encourage consumers to buy local produce. This is one way in which the links between Canadians and the food production system can be strengthened (see also Box 2.6).

When we eat at home, our cooking methods and habits affect the use of energy and natural resources. Most of the food dollar is spent on food consumed at home. A survey by the Beef Information Centre (1994) showed that 80% of evening meals for adults are "cooked from scratch" four out of five weekdays. Most Canadian households (93.9%) cook with electricity. Electric ranges vary drastically in energy use, depending on cooking patterns.

Cooking habits — for example, keeping the lids on pots, heating only the amount of food needed, and multitasking, such as filling the oven or using steamers so one element cooks a number of dishes — can improve energy use. Old-style recipes are often based on more efficient cooking methods. However, simmering a pot all day made sense when the wood burner was on all day anyway to heat the home. Today, many vegetables and sauces can be cooked by bringing the pot to a boil, turning off the power, and letting the food cook in its own heat.

Selection of household equipment appropriate for the cooking job also has an impact on energy use. Microwave ovens use 50% less energy than conventional ovens for small portions and defrosting; for larger quantities, the stove top is more efficient than the conventional oven (Earthworks Group and the Los Angeles Department of Water and Power 1990). Good maintenance of equipment enables efficient use of energy.

Of course, using hand-operated (i.e., non-electric) kitchen tools means less energy use. Since Toastmaster introduced the pop-up toaster in 1926, the number of small kitchen appliances has soared: toaster ovens, electric skillets and woks, waffle

makers, blenders, coffee grinders, and food processors, to name just a few. Some of these devices use resources in addition to energy. For example, many coffee makers use disposable paper filters, and some have activated charcoal filters that need to be replaced every 30–40 brews.

The way our society produces food and the way we consume it result in a great deal of waste. Some of this food waste is unavoidable; nevertheless, a lot of valuable nutrients and organic material end up in landfills or flushed into water courses. Some studies have shown that, at the household level, the amount of food thrown away is close to the amount of packaging thrown away (Ontario Ministry of Environment and Energy 1993). Animal products have the highest rate of waste (largely fat that is thrown out), followed by vegetables, cereal products, and fruit (WHO 1992). That these materials are not being reincorporated into the agricultural system may point to a long-term sustainability problem. Reducing and managing food waste so that the agricultural system as a whole is more efficient and stable would help ensure greater food security. For the consumer, one response is composting at home or supporting municipal and regional composting programs.

Some of the waste associated with food processing is being reduced by the 125 prepared and perishable food rescue programs in North America. Each year, these programs rescue about eight million kilograms of food that would otherwise go to waste (Anonymous 1993). One of the largest is Second Harvest, based in Toronto, which recovers about 500 000 kg of food each year. Leftover food from restaurants, grocery stores, and food processors is picked up and redistributed to charitable institutions and food banks. Some processors send food waste for composting or for use as animal feed.

Canadian consumers are part of the food supply chain. By careful selection and preparation of food items and management of food waste, we can help ensure that ecosystems can continue to supply food, along with clean air and water — the essentials of life. Consumers can also be advocates for a more sustainable food production and trade system and encourage the positive steps taken by farmers, governments, and industry.

Consumer Goods for Daily Living

Every time we buy a product, whether it is a durable product such as a colour television or a disposable product such as a newspaper, our purchase has an impact on the environment. For instance, it has been estimated that about 40 000 trees per day are needed to supply the paper for Canada's daily newspapers (Pollution Probe Foundation 1991). Raw materials, water, and energy are used to manufacture the product; other materials go into packaging; energy is used to transport and sell the item; often energy is used to operate it; and at the end of the product's useful life, there is almost always a quantity of material to be transported to the landfill. At every step of the product cycle, from manufacturing and distribution to use and disposal, there are ecosystem effects (see, for instance, Environment Canada 1995d).

Box 2.6
Country foods

Most Canadians get their food from stores. For some of us, this is supplemented by harvests from our own gardens or, especially for Aboriginal people, "country foods." Country foods are traditional foods garnered from land and water, such as game, wild birds, fish, and berries. A dietary study in two Native communities in northern Alberta showed differences in their consumption of traditional foods, which include tea, bannock, lard, and country foods. In the community with the highest consumption of country foods, these foods provided only 8% of the calories but a significant part of the nutrition (30% of protein, 30% of niacin, 22% of iron, 19% of riboflavin, and 17% of phosphorus). The high nutritional content of this food underlines its importance to the diet of Native peoples, especially those in isolated areas (Wein et al. 1992). If gardening and the harvesting of country foods are done appropriately, there is little stress on the environment, and individuals gain an appreciation for the natural processes underlying food production.

Rising expectations

Consumption is often equated with status. The quantity of goods necessary to maintain a "decent standard of living" seems to shift endlessly upward, and we seem to need more and more labour-saving products to allow adequate time for other activities.

In the 1931 Census, Canadians were asked if they owned one piece of household equipment — a radio. By 1971, the question was whether they owned a refrigerator, freezer, dishwasher, dryer, and a colour or black and white television. Even between 1982 and 1993, our aspirations and expectations with respect to household possessions changed dramatically (Table 2.2). In 1982, about 6% of households owned a video cassette recorder, and 10% owned a microwave oven; by 1993, the levels of ownership were 77% and 79%, respectively. Products like compact disk players and home computers were virtually unknown in the early 1980s; today, a significant percentage of households own these items as well. In 1982, only 16% of homes had an air conditioner; by 1993, the figure had risen to almost 26%, and many householders now regard an air conditioner as essential (Statistics Canada 1993a).

Major appliances: energy and water use

Energy use is one of the ways in which household appliances have an impact on the environment. The energy efficiency of household appliances varies from country to country. In Europe, for instance, appliances tend to be more energy efficient than in North America. Energy costs are often two to three times higher, and space limitations add to the demand for smaller sizes. In Portugal, 83% of households still have no refrigerator; in Greece, the figure is 74%. Clothes washer ownership in Europe ranges

from 43% to 95%. Clothes dryers are owned by 35% of households in Belgium, 34% in the United Kingdom, and under 5% in Portugal, Greece, Spain, and Italy (Lebot and Szabo 1992). The smaller proportion of appliance ownership may be linked to the lower incidence of two-income families, the more common pattern of daily shopping, and, in some cases, a warmer climate more conducive to drying clothes outdoors.

In Canada, appliances, excluding lighting, account for about 13% of home energy use (Natural Resources Canada 1994b). Older models are often less efficient than newer ones. In 1993, 18% of Canadian households had a primary refrigerator that was over 16 years old. In households with more than one refrigerator, 56% of the second refrigerators were more than 16 years old. Thirty-three percent of freezers and 18% of clothes dryers in use in 1993 were also older models (Natural Resources Canada 1994a). Although the energy efficiency of appliances is generally improving, demand is increasing for convenience features such as self-defrosting refrigerators, self-cleaning ovens, and large-capacity washing machines that are more energy intensive.

Energy consumption depends on how the appliance is used, how often it is used, and the technical standard of the appliance. For many appliances, technical standards have risen. Newer appliances tend to have better temperature controls and designs that allow consumers to reduce their energy use through choice of programs, operating modes, timing, and rates of usage.

Even for new models, energy efficiency varies. According to the estimate in Table 2.3, a household choosing the most efficient new refrigerator, range, dishwasher, washing machine, freezer, and dryer would save about $2 000 over the lifetime of the appliances compared with a household buying the least efficient new models. For most appliances, the energy to run them costs more over the lifetime of the appliance than the appliance itself (Natural Resources Canada 1993a).

Technological improvements are ongoing. For instance, a prototype heat pump clothes dryer can dry clothes with 60% less energy than a standard electric resistance dryer (Nadel et al. 1993).

There are numerous ways to reduce household water use. It has been estimated that four-fifths of total water consumption in the household is in the bathroom. Of that, half is used in the toilet. In Canada, the average toilet uses 20 L per flush; this compares with 9 L per flush in Germany and 6 L per flush in most of Scandinavia (D'Amour 1993). Toilets are available using as little as 2–4 L. In 1994, 42% of Canadian households had a water-saving showerhead, and 15% had a water-saving toilet (Statistics Canada 1995). Old, deteriorating plumbing fixtures also add to water waste. A dripping faucet may leak 30–100 L a day. Estimates are that household water leaks account for 5–10% of fresh water use (D'Amour 1993).

Information programs to make consumers sensitive to the cost savings in energy-efficient appliances and water-saving devices are sponsored by both utility companies and government. At the regulatory level, federal and provincial energy efficiency regulations will help eliminate inefficient energy-using equipment from the Canadian market. The regulations establish energy efficiency performance standards for specific equipment imported into Canada, manufactured and sold in the same province, or traded across provincial and territorial boundaries. Work is under way to expand

Table 2.2

Equipment in Canadian households, 1982 and 1993

Equipment	% of households owning equipment[a]	
	1982	1993
Air conditioner	16.0	25.7
Microwave oven	10.3	79.1
Gas barbecue	19.9[b]	51.9
Refrigerator	99.7	99.8
One	84.2	79.9
Two or more	15.4	19.9
Freezer	54.4	58.7
Dishwasher	33.7[c]	45.2
Washing machine	77.4	79.3
Clothes dryer	66.3	75.1
Automobile	80.2	77.5
One	52.0	53.7
Two or more	28.3	23.8
Van or truck	20.2[b]	28.4
Telephone	97.9	99.0
One	59.3	27.1
Two	30.9	36.9
Three or more	7.6	35.0
Radio	98.8	98.9
Colour television	84.8	97.7
One	72.5	51.7
Two or more	12.3	46.1
Cable television	58.9	72.4
Video cassette recorder	6.4	77.3
Compact disk player	–	33.2
Home computer	–	23.3

[a] Percentages may not add up because of rounding.

[b] 1984.

[c] 1983.

Source: Statistics Canada (1993a, 1994a).

the range of products covered under these regulations and to increase the minimum standards required for some products (G. Macpherson, Natural Resources Canada, personal communication).

Table 2.3
Comparison of energy efficiency of common appliances

Appliance	Energy use (kWh/year)		Lifetime of appliance (years)	Comparison between most efficient and least efficient	
	Most efficient appliance	Least efficient appliance		Amount less energy used by most efficient (%)	Savings over lifetime of appliance ($)
Refrigerator	564	972	17	42	502
Electric range	720	828	18	13	141
Dishwater	648	1 034	13	37	363
Washing machine	780	1 308	14	40	535
Freezer	348	420	21	17	109
Clothes dryer	828	1 128	18	27	391

Source: Natural Resources Canada (1993b).

Hazardous household products

Our choice of products and their use contribute to hazardous household waste, a load on the ecosystem affecting air, water, and, potentially, human health. Individuals often do not make the connection between "what's in the cleaning products they use and their own impact on the environment" (Kett 1993).

Estimates of the quantity of hazardous waste generated by Canadian households vary widely. As millions of Canadians are linked to sewage systems and have garbage disposal services, exact figures are impossible to determine. However, according to the British Columbia Waste Reduction Commission (1994), a common estimate is that a typical household produces about 6.8 kg of hazardous household waste a year. Estimates up to then ranged from a low of 4.3 kg to a high of 25.3 kg per year (Cadell 1993).

Data on the composition of hazardous household waste also vary, although there is general agreement on some of the main categories. Paints make up a significant proportion, ranging from 25% to 40% by weight. Pharmaceuticals typically make up about 5% of hazardous household waste, whereas pesticides represent 2–4%. Estimates of the amount of used motor oil, known to be a large part of hazardous household waste, range from about 10% to well over half the total (Cadell 1993). (The estimates cover such a wide range partly because of the different methods used in studies of this kind and partly because used motor oil is difficult to track or measure, as it is often simply dumped on the ground.) Approximately 250 million batteries are used annually in toys, shavers, clocks, radios, and so forth (Stevenson and Reeves 1991). When disposed of, they leak heavy metals and other toxic materials. While it is difficult to estimate the amount of household cleaners that end up in the environment, a large quantity is in use — sales amount to $1 billion each year (Felix 1993).

Sewage treatment plants do not remove many of the toxic substances found in hazardous household waste but pass them on to the rivers and lakes that supply our drinking water. Toxic substances in the landfill, on the driveway, and in the yard also eventually find their way into groundwater or surface waters. The Ontario Waste Management Corporation (1993) reports that, hectare for hectare, up to 15 times more pesticides are sprayed on city lawns and gardens than on country farms and fields.

Part of the hazardous household waste problem is leftover products; households create toxic waste when "empty" chemical packaging, aerosol cans, and other items are discarded. Appliances such as refrigerators and washing machines contain small quantities of such chemicals as polychlorinated biphenyls (PCBs) and CFCs. Although these products satisfy specified requirements for use, there can still be environmental and health side-effects and problems with disposal. That we need to take great care in how we handle and dispose of a lot of products and materials is demonstrated by the many Canadians who are hypersensitive to chemicals in pesticides and common household products.

Consumers often lack the information needed to identify which household waste is hazardous and how hazardous it is. This presents a major obstacle to proper treatment. With this in mind, important consumer actions include:

- choosing the best product from an environmental point of view;
- buying only the quantity needed and using it up or passing the leftover product to a friend who can use it; and
- taking toxic leftovers such as old paint or used batteries to a hazardous household waste depot.

Elimination of the use of toxic products in the household may be the best solution to the hazardous household waste problem. The British Columbia Waste Reduction Commission (1994) has recommended a "toxic traffic light" labelling system that would advise consumers of the environmental risks of certain household products.

Consumer goods and the economy

Consumer spending drives the Canadian economy, accounting for 60% of GDP (Statistics Canada 1993b). During the 1980s, household spending grew at a higher rate than personal disposable income. In the 1990s, the growth of disposable income has stalled, and consumption may be slowing. This has obvious negative ramifications for the economy. Reduced consumption will require major restructuring of jobs, industries, and lifestyles. Meanwhile, increased material and energy consumption on a global scale will further stress the environment and reduce the productivity of

> **Box 2.7**
> **Benefits of using recycled paper**
>
> *Recycling paper instead of making virgin paper:*
>
> - *reduces air pollution by 74%;*
> - *reduces water pollution by 35%;*
> - *saves 17.5 GJ (70%) of energy per tonne of paper;*
> - *saves 19–34 trees per tonne of paper [The number of trees varies with the type of pulp and paper made, species and size of trees, and other factors. The widely used figure of 19 trees is thus conservative for printing and writing paper.];*
> - *reduces landfill by 2.8 m³ per tonne of paper;*
> - *requires 90% less chemical compounds (e.g., bleaching agents); and*
> - *potentially creates more jobs, as collecting and processing recycled materials are more labour intensive than manufacturing products from virgin materials.*
>
> Source: Anonymous (1991); Thompson (1992).

ecosystems, which, in turn, will seriously affect the economy. It should be kept in mind, however, that not all forms of consumption have the same level of environmental impact. It is not so much the amount of money that is spent as the type of consumption that takes place that affects environmental sustainability.

In many areas, environmental goals can be furthered or attained if we focus on meeting needs rather than on producing a specific end product. For example, phone books are only one way of meeting the need for a telephone directory. By employing alternative formats, such as electronic communications, we can meet the need while reducing the use of paper and the associated environmental impacts. There are growing opportunities to use information technologies to meet objectives and to rely less on energy- and resource-intensive activities that are more environmentally harmful.

From an environmental perspective, excess packaging, disposable products, built-in obsolescence, fads and changing fashions, and goods too expensive or too difficult to repair all represent materials wasted. One of the responses is employing tradespeople to reuse, recycle, or repair what would otherwise end up in landfill (see Box 2.7). At the institutional and government policy-making level, efforts to instil product and packaging stewardship would help to ensure that consumers have access to quality products that are energy and material efficient. Instead of being an either/or trade-off, the jobs versus environment issue can be seen as an opportunity for both a thriving economy and a healthy environment.

Green consumerism

The "green" consumer has emerged as a key player in encouraging a move to a more environmentally responsible consumer marketplace. Green consumerism starts with daily decision-making. As people begin to think of excess packaging, energy inefficiency, and toxic household chemicals as harmful to their environment and life support systems, shopping becomes a more considered experience. A 1995 survey revealed that at least 50% of Canadian shoppers sought out products with recyclable packaging (60%), products labelled as "environmentally sound" (58%), or products labelled as "natural" or "organic" (50%) (Canadian Council of Grocery Distributors 1995). In 1992, more than 15% of Canadians identified themselves as green consumers; over 50% expressed some concern over the environmental impact of their purchasing decisions. Only 13% of consumers told pollsters that they were unconcerned about the environment (Statistics Canada 1994a).

Green labelling programs can help consumers make environmental choices. Canada's Environmental Choice[M] program now covers more than 65 product categories and more than 1 500 individual products. Products that qualify for certification and use of the EcoLogo[M] have less impact on the environment than conventional products. In 1994, 50% of Canadians recognized the EcoLogo[M] symbol (A. MacKenzie, Environment Canada, personal communication).

Canada's EnerGuide program provides information about energy usage and encourages consumers to think about the "second price tag" — the energy used during the lifetime of the appliance. Energy-efficient appliances save not only energy but other resources as well. Energy-efficient dishwashers and clothes washers use less hot water. Energy-saving dryers can extend the life of clothing. The EnerGuide label is a compulsory, standardized sticker on electric clothes dryers, clothes washers, dishwashers, ranges, freezers, refrigerators, and room air conditioners (Natural Resources Canada 1993b).

As helpful as standardized labelling is, its usefulness may be limited by a number of factors. An assessment of "what consumers want" rather than environmental impact determines which item the manufacturer or retailer is likely to promote. In turn, this promotion is highly pervasive in our media-rich age and tugs at our emotions and desires at many levels. On the other hand, in order to make environmental choices and to be able to compare different products, consumers often must do their homework — for example, by consulting consumer magazines.

Informed purchasing is only one way to move towards sustainability, but many people regard it as an important one. Consumers who buy an environmentally preferable product or defer their purchase help to reduce harmful impacts and put pressure on companies and governments to improve their practices.

Changing expectations

Is it possible to maintain or improve the quality of life without an ever-growing consumption of energy and material resources?

A large part of the answer rests on how we define "quality of life." There seems to be plenty of potential for individuals to switch to activities that are less environmentally stressful and yet fulfilling. There is also still much room for technological improvements, so that personal goals can be achieved at much lower environmental costs.

Within these frameworks, we can see that living sustainably does not necessarily mean returning to live in log cabins with outdoor privies and nothing but candles for light. However, it may mean a shift in attitude and behaviour so that there is less of a tie between consumption and status. A study by Environics Research Group Ltd. and CROP Inc. suggests that already fewer Canadians equate wealth with personal status (Chatterjee 1993). Like consumers in Japan and Europe, where consumer spending as a percentage of GDP is much lower than in Canada, some Canadians apparently make less connection between status and spending. An increasing percentage of Canadian consumers are looking beyond image and flash, expecting quality and dependability for their money.

TRANSPORTATION

The environmental impact of motorized vehicles is substantial. The burning of fossil fuels pollutes the air, and the building of necessary infrastructure such as highways consumes land and raw materials and leaves an enduring track in the ecosystem. At the individual level, the most immediate way we contribute to this impact is through driving automobiles.

In North America, our reliance on the automobile is legendary. The car has changed the urban landscape, spawning gas stations, auto supply and repair shops, new and used car lots, car washes, taxi companies, and driving schools, as well as offshoots such as fast-food restaurants, motels, and shopping malls. There are roughly 14 million cars in Canada, or approximately one car for every two people (Fig. 2.10). The corresponding figure for the United States is similar; for most European countries, it is two to six persons per vehicle. The average for Africa is 47 and for Asia 32, with wide variations among countries. Worldwide, the average is nine persons per vehicle (World Resources Institute 1994).

Here in Canada, the success of the automobile as a social icon and status symbol, as well as a mode of transportation, is demonstrated by the number of city dwellers who buy vehicles intended for terrain they will never encounter, or the popularity of cars that can go twice as fast as posted limits. Clearly, the choice of automobile is not always based purely on need. Nevertheless, consumer demand since the 1970s has led somewhat away from style towards safety, efficiency, and environmental features (Berton 1989).

Environmental impacts of the automobile

The automobile is a major cause of air pollution and other environmental impacts. In 1990, automobiles (referring to cars and other private passenger vehicles such as vans and small trucks) released 17% of the nitrogen oxides, 20% of the volatile organic compounds — major contributors to ground-level ozone — and 47% of the carbon monoxide emitted in Canada. In 1992, the automobile contributed 13% of the country's carbon dioxide emissions, the primary global greenhouse gas (Environment Canada 1995a). Testing by British Columbia's Ministry of Environment, Lands and Parks and Environment Canada under the AirCare program in 1992 found that 54–70% of vehicles on the road in the Lower Mainland had emissions-related defects (Goodall 1992).

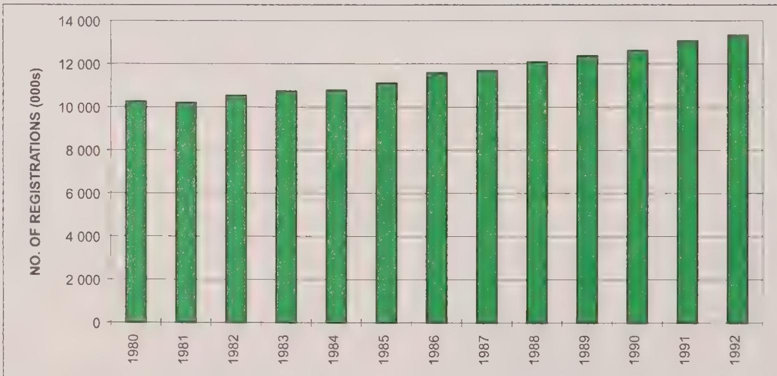
Cars also use up a lot of land. Streets and parking lots comprise 35–50% of the land in large cities, and one interchange can occupy as much as 30 ha (Berton 1989) (see also Box 2.8).

Automobile use in Canada continues to rise. Between 1950 and 1992, the total number of kilometres travelled by passengers in automobiles in Canada increased from 71.9 to 361.1 billion passenger–kilometres (Environment Canada 1995a). An average vehicle in 1992 was driven 16 844 km, the equivalent of two and a half times from coast to coast. On average, Canadians spend 328 hours a year inside their car; the estimate for young males is much higher (Harvey et al. 1991). In spite of the improved fuel efficiency of newer cars, the total fuel used has grown almost five times since 1950 because of our increasing use of the car (Environment Canada 1995a).

World use of motor vehicles has also expanded significantly in a very short time. In 1950, fewer than 50 million cars were on the world's roads, 85% of them in North America. Today, the number of cars exceeds 500 million. Much of this increase has been

Figure 2.10

Total passenger car registrations, 1980–1992



Source: Statistics Canada (1994a).

outside North America, from 7 million cars in 1950 to 125 million by 1980. The world's vehicles use one-quarter of the world's energy, cause over 250 000 fatalities and uncounted injuries annually, and release 13% of global carbon emissions as well as local pollution (Walsh 1991). The demand for motor vehicles continues to grow, especially in developing countries, where vehicle pollution controls are virtually nonexistent.

Box 2.8
Environmental impacts of cleaning the automobile

In the early part of this century, cars were waxed with beeswax and carnauba (from a palm tree grown in Brazil). Today's waxes, polishes, and sealants often contain toxic chemicals and solvents that release volatile organic compounds into the atmosphere.

The amount of water used to wash the car depends on the washing method (Table 2.B3).

Table 2.B3
Water consumption by method of car washing

Method used	Water consumption (L)
Nozzle off, hose running the whole time (20 minutes)	360
Pistol-grip nozzle that is shut off except for wetting and rinsing	60
Pail of water	Under 20

Source: Weseley (1993).

Commuting

Canadians continue to opt for the automobile to get to work and back home again. Seventy-four percent of Canadians drive to work, whereas only 15% take public transport, 2% cycle, and 9% walk (Fig. 2.11). The fact that air pollution indicators are widely broadcast does not seem to have reduced automobile commuting; both a decline in ride sharing during the 1980s and a shift away from public transit in the 1990s have occurred across North America (American Public Transit Association 1993; Canadian Urban Transit Association 1993; Ontario Ministry of Transportation 1993).

Increased use of public transit has the potential to lighten the detrimental impacts of the automobile: one bus replaces 44 cars, reducing traffic congestion, material use, and pollution (Goodall 1992). Although more than three-quarters of Canadians live in areas served by public transit, public transit accounts for less than 5% of motorized travel within urban areas (Environment Canada 1995a).

One trend with potential environmental benefits is working from home. Estimates of the number of Canadians working at home vary, depending on how it is defined. If workers spending one or more days at home, self-employed workers, and those who did either primary or secondary work at home are included, as many as 23% of Canadian workers may be said to work at home (Centre for Human Settlements 1995). In the 1991 Census, however, only 1.1 million Canadians reported that their usual place of work was home, and a quarter of these were farmers. A 1991 Statistics Canada survey indicated that 6% of employed Canadians worked at home some or all of the time. Many of these, such as real estate and insurance agents, have always worked from home (Akyeampong and Siroonian 1993). If the definition of working at home is more restrictive, the number of paid teleworkers or telecommuters is probably around half a million (Chamberland 1994). There would seem to be a great deal of potential for more Canadian workers to take up telecommuting.

Reducing the environmental impact of the car

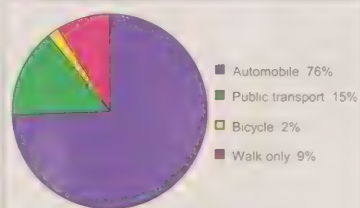
Lifestyle and technological changes both hold promise for reducing the environmental impact of our transportation systems. Improved engine design and pollution controls, lightweight vehicle construction, and alternative fuels could all contribute to substantial reductions in transportation energy use.

The question of alternative fuels raises many issues. While some alternatives may seem advantageous at the vehicle level, the value of massive conversion to a new technology may not be so clear when all the relationships are considered. Ethanol, for example, is an effective fuel supplement. However, if Canada were to convert completely to ethanol fuel, there would be heavy energy requirements and demands on agricultural land to raise and process the crops required for fuel. The associated environmental stresses could offset the use of the somewhat cleaner-burning fuel.

Technological improvements are potentially significant. Nevertheless, total fuel use and emissions are increasing in spite of the fact that there are more fuel-efficient cars on the road. The growing environmental impacts are mostly due to the increased use of the car.

There are many reasons for our widespread reliance on the automobile. The layout of urban areas, with separation of home, services, and the workplace, has been done with the automobile in mind. This, in turn, makes car use almost a necessity (see also Chapter 12). Glamorous ads tout the car as a status symbol and

Figure 2.11
Primary modes of commuting between home and work in Canada, 1991



Source: Statistics Canada (1994a)

form of entertainment. While owning a car is expensive — the Canadian Automobile Association estimates the cost of owning and driving the average car in Canada to be $7 715 a year (CAA 1995) — public transit is often inconvenient compared with access to a personal vehicle, and the actual ongoing cost of fuelling an automobile has gone down (Fig. 2.12).

What can concerned Canadians do to lower the car's environmental impact? At a simple level, emissions and energy use can be reduced by lowering speed limits, modifying driving behaviour, and paying greater attention to vehicle maintenance. Consumers can buy the best available technology on the market. More significantly for the future, they can pressure governments and industry to establish rigorous standards and targets to guide technological development and application.

But probably the most important contribution that individuals can make to lowering environmental impacts is to reduce their use of the automobile. Simple tactics include better planning to avoid the need to "pop out" to buy forgotten items, walking short distances instead of driving, combining a number of activities into multiple-chore trips, and carpooling. Using public transit rather than the personal automobile will have the greatest impact on urban air quality.

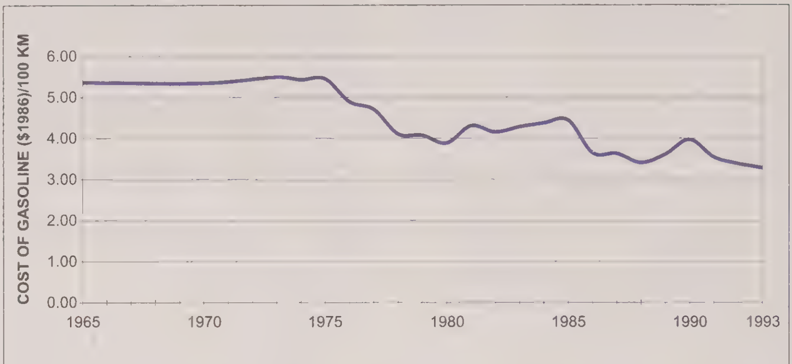
Comparisons with other countries show that these modifications in the use of the automobile do not necessarily imply a loss of convenience. Figure 2.13 shows that gasoline consumption per capita is substantially higher in Toronto (and in U.S. cities) than in major Australian or European cities that enjoy a comparable quality of life. And Canadians are generally willing to try to reduce their use of the car (Fig. 2.14). As mentioned, however, existing infrastructures often do not make it convenient.

Movement at the institutional level will help bring about consumer adjustments in behaviour. This is beginning to be visible in such expressions of direction as "New Visions in Urban Transportation," a recent conference at which participants envisioned mixed-use development where walking, cycling, and transit are all facilitated (Transportation Association of Canada et al. 1994).

Transportation is one area in which it is obvious that concerted effort at all levels, from the individual to the institutional, will be required for any significant change to come about.

Figure 2.12

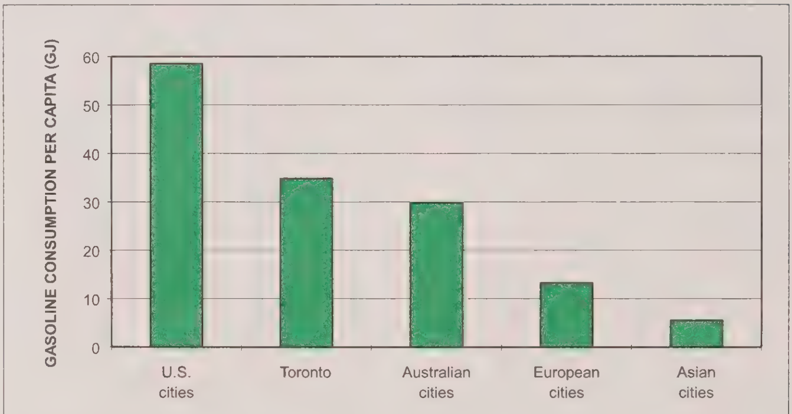
The cost of fuel required to travel 100 km in an average new automobile, 1965–1993



Source: Adapted from Environment Canada (1995c).

Figure 2.13

Per capita urban gasoline consumption



Source: D'Amour (1993).

PUBLIC CONCERN ABOUT THE ENVIRONMENT

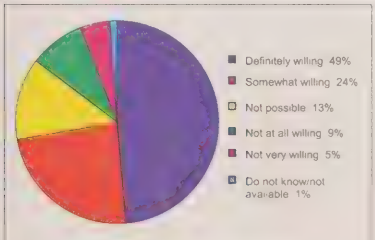
While issues such as employment and the economy have been on the top of people's minds in recent Canadian surveys, Canadians generally express a strong underlying concern about the environment when specifically asked to rate its importance (Table 2.4). This depth of environmental concern is to some degree reflected in our everyday actions. The Canadian Environmental Network database contains

more than 2 000 listings of environmental groups (Canadian Environmental Network 1994), almost all of which are supported by donations of money and time from Canadians. A high percentage of those served by municipal solid waste recycling programs participate in such programs (Statistics Canada 1995). And environmental awareness in the marketplace continues at a relatively high level (see "Green consumerism" above). As a result of consumer demand, Canada has also been a world leader in green product introductions (Table 2.5).

In 1993, 76% of Canadians told pollsters that they would pay at least 10% more for "green products"; this was an increase from 66% in 1989. A very high number (87%) of Canadians said they would pay more to avoid harmful household products such as paint (Angus Reid Group 1994). Yet actions speak louder than words. A number of studies show that expressing concern and changing behaviour are not always linked. For example, a 1991 Nielson report indicated that "environmental products" were not selling particularly well (Moore 1992). Other studies suggest that, to date, only about 20% of Canadian consumers have been ecologically concerned enough to make more than superficial changes in their lifestyles. The other 80% consider environmental benefits only after other product attributes such as price, effectiveness, ease of use, familiarity, and convenience (Moore 1992).

Figure 2.14

Willingness to walk or bike (instead of drive) twice more per week



Source: International Environmental Monitor Limited (1995)

Table 2.4

Public opinion of the relative importance of various public policy issues, 1993

Issue	Importance score out of 10
Unemployment	9.63
Economy	9.47
Crime	8.97
Environment	8.86
Taxes	8.78
National unity	6.87

Source: Creative Research International Inc. (1993).

Table 2.5

Introduction of green products, by country

Country	Green products introduced as a % of total introduced packaged goods						
	1986	1987	1988	1989	1990	1991	1992
Canada	2.0	0.6	1.1	4.6	16.4	33.9	9.4
Australia	0.3	–	2.9	3.1	12.3	5.1	5.9
Europe[a]	0.7	0.9	0.7	2.4	5.7	3.2	4.7
Japan	0.2	0.7	1.6	1.8	1.5	0.8	5.4
United Kingdom	0.9	2.4	4.0	8.3	10.8	7.2	5.1
United States	1.1	2.0	2.8	4.5	11.4	13.4	11.5

[a] "Europe" refers to Denmark, France, Germany, and Italy.

Source: Productscan database, Marketing Intelligence Service, Naples, New York.

Information and education

Information and education are the keys to the knowledge, skills, and values that individuals need in order to make direct connections between everyday activities and major environmental issues.

Agenda 21, released at the 1992 Earth Summit in Rio de Janeiro, listed education-related objectives for the countries of the world (UNCED 1992). These included the provision of environment and development education from primary school through to adulthood and integration of environmental issues into all aspects of education — both formal and informal — particularly as they apply to the local context.

Canadian schools and educational institutions are beginning to implement this approach, to a greater or lesser extent. For example, the proportion of Ontario schoolchildren who have access to specialized field centres for teaching environmental studies increased from virtually none to 20.6% in 1988–1989 (Eagles and Richardson 1992).

Despite this progress, a study of teachers in Ontario schools (Eagles and Richardson 1992) identified the following as barriers to teaching environmental issues:

- lack of time to prepare;
- lack of suitable instructional materials;
- apprehension about their own competence in the field; and
- reluctance because it is not their direct responsibility.

As well, school board budget limitations may threaten the continuation of existing environmental programs.

Environmental studies are popular at the postsecondary school level. The number of graduates from these programs at Canadian universities is increasing, and the number of programs in environmental

technology at community and technical colleges has grown in the early 1990s (Eagles and Richardson 1992).

The largest group of Canadians, adults outside the formal education system, has access to continuing learning opportunities and information through libraries, on-line services, environmental groups, governmental and nongovernmental organizations, interpretive programs at national and provincial parks, religious institutions, and the media.

The National Round Table on the Environment and the Economy, as well as provincial round tables and the Winnipeg-based International Institute for Sustainable Development, are all active in promoting education on sustainable development. Canada's National Environmental Indicators program is aimed at making concise information on key environmental issues available for decision-makers at many levels.

In addition, several provinces and cities have published state of the environment reports to inform their citizens about priority environmental issues. Many communities have local round tables or other multistakeholder groups involved in the creation of a sustainable development strategy for the community.

It is important that information programs be well researched and relevant. A common type of educational message, presenting consumers with lists of do's and don't's, may do little to enable consumers to make decisions for themselves. We know from adult education theory that adults learn best when they have a particular purpose in mind for the knowledge. To be effective, educational programs should directly address personal needs and aspirations.

The most important and most difficult challenge in preparing an educational program is ensuring the accuracy of the material. Myths abound. Common myths in educational packages relevant to the Canadian lifestyle include:

- "it's easy to tell which product is better for the environment" (it is not);
- "recycling is good" (it might have been better not to buy the product in the first place); and
- "packaging is bad" (some packaging reduces waste such as food spoilage).

Consumers are faced with complex decisions and difficult trade-offs. They need educational programs that explain the issues without oversimplifying them. Some issues may benefit from a variety of opinions and approaches because there may be no "right" answer; on other issues, there are sufficient reliable data available to enable consumers to make an informed choice. Well-researched information will be broadly accepted if it is from an impartial source and it is presented in an accessible format.

TOWARDS MORE SUSTAINABLE LIFESTYLES

A Worldwatch Institute study estimated that the whole world could live in the style of the average European in the mid-1970s if fossil fuels were used in the most energy-efficient way and renewable energy sources were maximized. The standard of living would consist of modest but reasonable comfort: small but not crowded accommodation, refrigeration, automatic clothes washers, access to adequate hot water, and use of public transit supplemented with some private automobile use (Durning 1992).

Models such as this are only rough estimates: they assume complete uniformity and do not take into account socioeconomic and regional differences or possible technological change. They do provide a perspective, however, on what an "average" sustainable living standard might be, and they remind us of the vast inequities in living standards that now exist globally. Such models also indicate the direction in which developed countries with a goal of environmental sustainability should be headed: less emphasis on material consumption and more emphasis on resource- and energy-efficient technologies and economic systems that account for environmental costs.

> *"The enormity of the challenge and the level of uncertainty must not be seen as a cause for despair and inaction. We have more than enough information already to demonstrate the need for action, and the initial solutions are both obvious and simply applied. What is still lacking is the will to act."*
>
> — Royal Society of Canada (1993)

The lifestyle choices of Canadians are personal decisions, influenced by individual values and circumstances. Not every Canadian lives in the same way, and it would be impossible to define an ideal sustainable lifestyle appropriate for everyone. Yet if changes do not come, environmental degradation will continue and possibly accelerate.

How much responsibility for making those changes does the individual have to take on? We all make countless decisions every day about what we buy, how we dispose of waste, whether we walk or take the car, and so on. Some individuals will make concerted efforts to reduce their contribution to environmental stress by, for example, bicycling to work, buying green products, and recycling used containers. Others will go one step further, perhaps by choosing to purchase a "greener" car or doing without a car altogether.

Yet our choices are limited by the way production is organized in our economy and the values and assumptions built into our society. Individuals and society as a whole are two different entities that continuously influence each other and that are constantly evolving as they track each other's shifts: for example, while consumers complain that manufacturers are not providing adequate choices for a "greener" car, automobile manufacturers claim they are only responding to consumers' demands. One is

very difficult to change without change in the other. It is important, then, that lifestyle change be considered in the context of change in the social system, including the production and supply of goods and services. As highlighted in *Agenda 21* of the 1992 United Nations Conference on Environment and Development, encouraging sustainable consumption patterns and lifestyles requires the combined efforts of governments, consumers, and producers (UNCED 1992).

There is no easy way to change a society in which habits and behaviours are strongly ingrained. To make change happen, a conscious effort will have to come from all quarters. Institutions must choose to incorporate environmental sustainability as an objective in decision-making, and individuals must try to influence society as consumers, workers, taxpayers, and voters. While seriously considering what defines "quality of life" for them, individuals need to consider ways to encourage sustainable patterns of production and consumption. At the personal level, this can consist of three areas, two of which are a form of "substituting":

1. First, individuals can substitute behaviours that result in less energy and material use, waste production, and ecosystem degradation, such as commuting by transit or bicycle instead of using an automobile to go to work.

There is the ongoing question of where the emphasis should lie and how much change will be enough. Answers do not come easily. For instance, some would argue that consumption must be severely cut back and that discussion about issues such as alternative purchasing essentially just encourages consumers to continue to buy. From this perspective, the reduction of our desire for material goods is paramount. This is where an examination of what defines quality of life can be important. Achieving progress along these lines may call for a weakening of the link our society makes between personal status and consumption. Owning fewer material goods may seem inconvenient, but there can be trade-offs. Perhaps more time with the family or more opportunity for cultural events is possible.

2. Secondly, individuals can substitute more efficient technology or use products that have less environmental impact throughout their life cycle to achieve the same end, such as using smaller, much more fuel-efficient automobiles.

While new conservation-related technologies are likely to help us achieve lifestyles that are more sustainable, technology can be a double-edged sword. Only if its objectives include energy efficiency, resource efficiency, and low waste output will a technology assist us in achieving environmental sustainability. Also, this second form of substitution is not purely technical. Better products or technologies may also involve behavioural changes, and individuals and society may need to adapt. For example, there is already a range of technologies that could be applied to the design and building of a home to make the way we live more sustainable — one example is the Toronto Healthy House. Living in such an optimally designed green home would involve a somewhat different lifestyle from what most Canadians are used to — such as having to maintain a composting toilet.

3. Finally, in terms of our relationship to society and its institutions, individuals can ask for appropriate information and insist that products, services, and planning at all levels be based on an understanding of environmental implications as well as other factors.

Encouraging the dissemination of appropriate information can be difficult. As we have seen, there is not always consensus on how to manage a given area — such as food production — more sustainably. The individual can help shed some light on the questions by encouraging government to support impartial information gathering and dissemination.

Individuals, as consumers, can encourage producers to demonstrate in a clear, understandable way how they are incorporating environmental considerations into their production processes through such things as environmental impact analysis and product life cycle management. The cost of products and services is also a form of information and an important basis for consumer decisions. When water is priced by the amount used rather than a flat rate, for example, consumers are more likely to conserve (Environment Canada 1994). Where possible, governments and industry should build environmental costs into the prices consumers pay.

Also, individuals can insist that cities and towns be planned with more of an emphasis on infrastructure and designs (e.g., less sprawl and more efficient transit) that allow and encourage people to meet their own needs and aspirations while having minimal impacts on the environment.

It may not be possible to eliminate all pollution. However, sustainable development requires that we be aware of the environmental effects of our activities and both plan and take action now to reduce those effects. While the debate continues as to whether drastic action is required, individuals can at least attempt to make appropriate changes in their lives and encourage institutional initiatives locally, nationally, and globally.

Sustainability requires a balancing act between meeting our needs and wants and maintaining healthy ecosystem functions. There are ways for individuals to meet their needs and aspirations that are less demanding on the Earth's life support systems. There are also opportunities for individuals to reexamine those needs and aspirations. Ultimately, however, society as a whole must support these kinds of adjustments if they are to be widespread and effective. There is little in our world that will not benefit from being rethought in light of the need for sustainability.

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THE STATE
of
CANADA'S
ENVIRONMENT

1996

PART II

CANADIAN ECOZONES

INTRODUCTION

> *"A primary challenge for everyone is to think fundamentally, to get to the roots of our relationship with the planet.... To see beyond the bits and pieces that are taken to be wholes, to understand more comprehensive surrounding realities, has become an essential task."*
>
> — J.S. Rowe (1990)

THE LARGER PICTURE

Most Canadians — about 77% of them — live in cities. Buildings, roads, utility lines, vehicles, and other people surround us. Apart from some parks and other urban green spaces, the "environment" is something that for the most part exists elsewhere, at some distance from the urban core.

Seen from space, however, Canada shows no roads, no political boundaries, no languages, no politics, and no people. The country's appearance is strikingly different from this distant perspective (Fig. II.1). It is surrounded by three massive oceans, contains a large share of the world's fresh water, and has 25% of the world's major wetlands. Vast stretches of land are occupied by the Arctic barrens, great plains, forests, and the western mountains. Ocean currents swirl around the margins of the continent, and weather patterns move over the land and ocean masses. Virtually hidden from this distant view are tens of thousands of species of plants and animals, as well as more than 28 million human beings.

This faraway view of the nation is compelling, because it forces us to think of ourselves as an integral part of the Earth's ecosystems, not separate from them. Just as images taken from space are relatively new, so too is the broad realization of the human partnership with the environment. Although some people have long recognized the need for an integrated or holistic understanding of ecosystems, most have only recently come to understand the urgency of the need for such an approach.

Figure II.1
A Canadian perspective

Source. State of the Environment Directorate, Environment Canada

From bits and pieces

Glimpses from satellites and space shuttles remind us of the big picture: that we live within broad ecological zones on the Earth's surface. Ironically, our knowledge of those ecosystems has grown through a process that emphasized studying the bits and pieces and disregarding the whole. The human activities associated with these ecosystems have therefore reflected a similar preoccupation with the parts rather than the whole.

As one of the largest nations on the globe, Canada has a diversity of landscapes and seascapes that is seemingly endless — temperate forests and Arctic barrens, extensive river systems and coastlines, vast plains and imposing mountain ranges, farmscapes and wilderness, wetlands and deserts, immense lakes and prairie potholes, ranging from relatively untouched to highly stressed systems. The variety can be overwhelming.

Naturalists, scientists, and many others have contributed to descriptions of these natural zones. Their points of view and

immediate interests differed over time. Some assessed the different landscapes and seascapes for the extent and quality of timber, wildlife, hydroelectric, and agricultural resources; others described what they were trained to see as biologists, foresters, geologists, or other professionals.

A wealth of maps and reports emerged. Some described biological features such as general vegetation, forests, wildlife, habitat, and peatlands. Physical descriptions focused on climate zones, bedrock types, marine areas, permafrost patterns, landforms, and soils. Other classifications specifically addressed types of human activity (e.g., rural land uses or urban settlements) or cultural groupings (e.g., Inuit region). These thematic or single-purpose studies are quite reliable tools for studying component parts of ecosystems. However, in cases where it is important to understand the relationships between people and the environment, between wildlife and wildlife habitat, and between carrying capacity and resource use, the existing information tends to be rather piecemeal.

Problems with an incomplete view

Studying the component features of ecosystems has contributed to our understanding of Canada's biological and physical diversity. For the purposes of environmental management and sustainable resource use, however, this piece-by-piece approach has led to an incomplete and often misleading view.

There are those who are involved in the planning and management of ecosystems, and there are others who look at ecosystems from the standpoint of impact assessments, sustainability strategies, environmental indicators, economic factors, monitoring systems, or public reviews. There is so much work to be done in all these separate areas that we have been slow to develop an integrated and holistic approach. Yet without a broad ecosystem perspective, it is becoming increasingly difficult to address environmental goals. Many interests are at stake, and there are short-term and long-term considerations — land and water uses to be balanced; conservation and exploitation perspectives to be weighed; local and distant benefits and costs to be assessed; cumulative effects to be measured; and political, social, environmental, and economic values to be evaluated. Understanding the wide ecosystem context is vital today.

The boreal forest ecosystem can be used as an example to illustrate why a holistic approach is necessary (Natural Resources Canada 1995). Success in resolving issues and meeting sustainability goals will depend upon balancing a variety of interests, including harvesting timber; protecting natural areas and biodiversity; maintaining recreational values; protecting the habitats of fish, mammals, birds, and other wildlife; conserving water quality; acknowledging traditional land uses; and supporting hydroelectric and mining developments. Which types of activities should have priority? How much of the forest should be allocated to what use? What will be the effect on jobs? What will be the local or perhaps the global environmental impacts of these activities? How will acidic pollutants from distant sources be controlled? Should natural forest fires be managed? Will control of forest insects have adverse effects on fish habitat or songbirds? Is forest renewal keeping pace with forest harvesting? Are the forests sustainable?

Answering these questions is a difficult job, requiring the cooperation and skills of many groups. Decisions also need to be supported by comprehensive information about ecosystems. The recent focus on depicting natural zones according to ecosystems addresses this need. It builds upon previous studies but places a greater emphasis on understanding the relationships among the different pieces.

AN ECOZONE PERSPECTIVE

Many tools are used to convey the notion of ecosystems and their all-encompassing nature. Because people are accustomed to thinking in terms of defined spaces, to seeing their lot, municipality, or country represented on a map, depicting ecozones on a map is a fundamental starting point. Political maps show legally delineated spaces, such as city or provincial boundaries, but this type of mapped information is not of primary importance in the early stages of applying an ecosystem approach. In contrast, ecozone maps define spaces in an ecologically meaningful way. Expressing ecosystems as units on a map provides a basis for understanding their structure and composition.

In the 1970s and 1980s, professionals from governments, nongovernmental organizations, universities, and industry worked through the Canada Committee on Ecological Land Classification to establish a common system for classifying and mapping terrestrial ecosystems. This resulted in a hierarchical classification system applicable to everything from broad-scale ecozones to detailed ecosections (Environmental Conservation Service Task Force 1981). This cooperative effort has paid off. Many jurisdictions and professionals across Canada now apply this system to describe and map ecosystem units. The classification system has been used to provide a country-wide through to a local perspective as well as to describe ecosystem types from the general to the specialized. In the early 1990s, a concerted federal, provincial, and territorial initiative updated earlier maps and descriptions (Ecological Stratification Working Group 1996).

The ecosystem units are used like a comprehensive set of information folders. The folders allow different agencies and jurisdictions across Canada to contribute their expertise and information on particular elements of ecosystems. They also allow people to draw from the expertise of others. The ecosystem units have become a common protocol to build a profile and understanding of Canada's ecosystems.

A delineation of marine ecosystems was completed recently (Marine Environmental Quality Advisory Group 1994). The processes involved were similar to those used in the terrestrial classification.

Common sense and concepts

What is meant by an *ecozone*? People intuitively capture the meaning by the

simple phrases they use to describe the large ecological areas of which they are a part. For example, consider all the attributes and relationships that are implied by phrases such as the prairie grasslands, the Plains Indians, the great central plains, Canada's breadbasket, the ranching heartland, home of the buffalo, the nation's largest farmscape, prairie climate, grassland soils, big sky country, and prairie wetlands and potholes.

Beyond expressing something about the obvious characteristics of the area, these phrases fashion a broader impression of a specific geographical location and of a vast open space. The mere word "prairies" evokes an image of large expanses of grain or rangelands that cover the southern parts of Alberta, Saskatchewan, and Manitoba. The phrases equally help to describe particular biophysical features and underlying relationships. The prairies have been a valued cereal grain production area for many decades. What interactions among environmental, economic, and cultural elements have caused this to be so? Many connected factors explain why the region is so productive for agriculture — the deep and nutrient-rich soils, the extensive tracts of flat or gently rolling land, the inherent adaptability of grassland species, the ease of cultivation, the warm, dry climate, and so on. Common sense tells us about the uniqueness of an area like the prairies, the mosaic of particular characteristics, and the inherent relationships that exist in that zone.

An ecozone, then — like any ecosystem — is an *area where organisms and their physical environment endure as a system*. Because of the large size of ecozones, the types of criteria that are used to define them are geared to broad, common characteristics. For instance, plants would be defined by major plant formations (e.g., boreal spruce) rather than by more detailed classifications such as plant communities (e.g., Black Spruce–Feather Moss community). Landforms and soils would be defined in a similar way, by large physiographic divisions (e.g., mountain ranges) and soil orders rather than by local landforms (e.g., a specific hill) or soil series.

Ecosystems may endure or remain the same over long periods of time, but they are not completely fixed or static. The simple dynamics of the changing seasons bring forth striking changes. Other, long-term changes can be gradual, cumulative in their effects, and dramatic in their impacts. For example, the northern boreal forest ecosystem conveys an unyielding image of endless forests of spruce and fir. Yet the Canadian Shield is subject to repeated forest fires and widespread insect damage. When a fire has been severe, grasses, flowers, and shrubs may carpet the landscape, native animals may have been driven away, and productive soil layers may have been depleted. This early renewal stage will eventually be replaced once again by a mature forest. In fact, some trees actually require forest fires for their survival.

Moreover, ecosystems can be of any size. They are not equal in kind or in the variety of their characteristics. They may refer to local wetlands, the Gulf of St. Lawrence, the circumpolar Arctic area, or the entire ecosphere (i.e., the Earth). Big or small, they are part of a continuum — like a family, a community, or a nation — the components of which interact with and affect one another. The trends and conditions that are associated with the bigger ecozone units must be put in the context of what happens locally in smaller ecosystems (i.e., in ecodistricts), as well as in ecosystems of global scale.

If the reproduction of eastern migratory birds is weakened, for instance, the effects of the population declines reverberate throughout North America. Local and global events and conditions are linked by the age-old processes of nature as well as by human activities. The Arctic ecozones are affected by ocean ecosystems that originate from as far away as the equator, by migratory birds that winter in Mexico, and by pollution that emanates from Russia's industrial heartland. On the west coast, forestry operations can cause soil erosion that impairs salmon breeding grounds; if the salmon population is not renewed, the decline in numbers will adversely affect the coastal fishery in three to five years.

Where the edges meet

Driving from Banff to Calgary or from Kenora to Winnipeg, one moves from a forested ecozone to a grassland ecozone. The two ecozones are very distinctive, but the transition from one to the other is gradual for the most part. Along the way, the trees become smaller and fewer in number, the land begins to flatten, land use activities change, rock outcrops disappear, the soil changes texture and becomes more abundant, and the landscape appears drier. Ecosystem boundaries at any level of definition are in reality not lines but transition areas where one set of biophysical features (i.e., plant and animal communities, climate regimes, human activities, and soils) gradually gets replaced by another set. The boundaries on ecozone maps approximate the transition zone, but the gradation typically involves tens of kilometres.

For this reason, the exact location of the boundary lines on the map is not what is important; what *is* important is using the map as a tool for assessing the characteristics and management of the different ecosystems. Moreover, the boundaries should not be thought of as barriers — they are not fences barring interaction between ecosystems. Many of the dynamic relationships that sustain a particular ecozone arise from distant or neighbouring ecosystems. Weather fronts that affect the west coast mountains may originate far out in the Pacific. Rain and snow that fall within the prairie catchment will become the waters that flow into the boreal forest and then into the Arctic. Caribou that summer in the Arctic will move into the boreal forest to winter. Boundaries are simply a way of demarcating areas that have different characteristics.

Defining ecozones

How is an ecozone determined? What are the key diagnostic characteristics for each Canadian ecozone? Are the same characteristics used for each? Which characteristics are essential, and which are incidental?

In part, the answer to these questions is based on what common sense would suggest. In any large ecosystem — the forested mountains of the west coast, the Arctic

lowlands of the Northwest Territories, the Great Plains of the Prairie provinces — the particular combinations of characteristics such as climate, landforms, soils, plants, animals, and human activities are distinctive. These combinations remain relatively constant for each ecosystem.

Standards and guidelines exist for describing ecosystems (Environmental Conservation Service Task Force 1981; Wiken 1986). Ecozones still have to be judged on a case-by-case basis. Characteristically, they are large units (i.e., greater than 200 000 km^2). Most of the diagnostic features are factors normally thought of as natural — landforms, soils, water features, vegetation, climate. However, where human activities are extensive and are key to sustaining the character of the area, they are also diagnostic. Agricultural activity is a fairly diagnostic feature of the Prairies ecozone; the occurrence of certain types of soils, the plains physiography, the former extent of native grasslands, and other features would also be considered in determining the boundary and traits of this particular ecozone.

Human activities and the environment

Social and economic activities are often directly associated with the environmental attributes of an ecosystem. Forestry is invariably linked with forested ecosystems, agriculture with agroecosystems, and fishing with aquatic ecosystems. Timber harvesting relies on ecosystems having soils and climates that will support productive tree growth and large quantities of harvestable trees.

Other human activities are not directly linked to the resources within a particular ecosystem. For example, most manufacturing and service industries are located in Canada's warmer ecozones. As these industries grow, so do transportation corridors, power supply networks, and other infrastructure. Large manufacturing operations and urban settlements may rely on distant ecozones for resources and energy, and they have an impact on both local and distant ecosystems through their waste disposal, energy use, water consumption and treatment, and automobile emissions.

Diversity of Canadian Ecozones

Canada has a mosaic of distinctive ecosystems, many of which are unique in the world. There are 20 major ecosystems — ecozones — in Canada: 15 terrestrial ecozones and 5 marine ecozones. The legend on Figure II.2 arranges the ecozones according to general shared properties. For instance, all of the marine units are grouped, as are the boreal and Arctic units.

Ecozones vary in shape and size. The largest in Canada — the Boreal Shield ecozone — is an irregularly shaped area stretching across parts of six provinces. It is bigger than the state of Alaska, the country of Mongolia, and the province of Quebec. It takes less time to fly from New York to London, England, than it would to fly the length of the Boreal Shield ecozone. Canada's three Arctic ecozones, which occupy diagonal bands across the North, collectively cover an area more than four times the size of France. The main wetland-dominated ecozone — the Hudson Plains ecozone — is larger than Italy and is the world's largest wetland area.

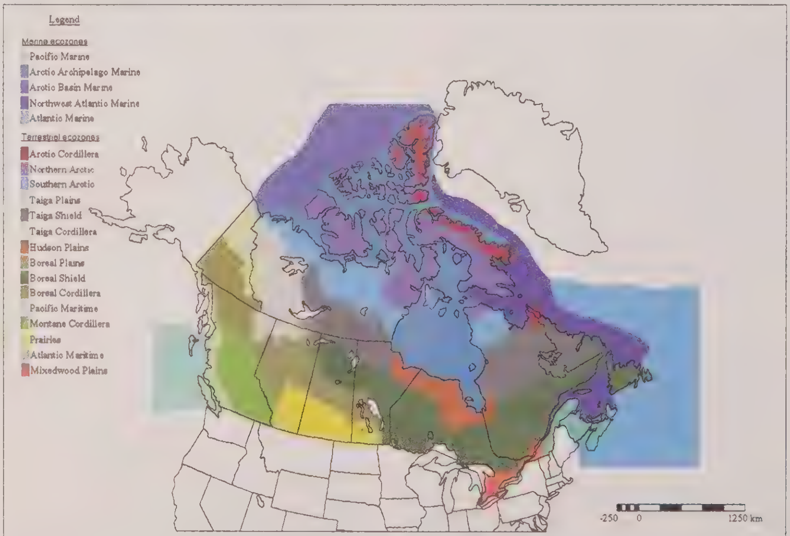
Ecozones vary in diversity as well. For instance, the Prairies ecozone is less diverse than the Pacific Maritime ecozone. The Pacific Maritime unit is a lot like a layer cake. Temperate rain forest dominates much of the lower and mid elevations, but the base includes areas such as semi-Mediterranean arbutus and Garry Oak woodlands, whereas alpine meadows and snow packs dominate several layers higher up.

Ecozones also differ with respect to their opportunities and constraints for particular activities and uses, such as agriculture, forestry, fishing, and recreation. For instance, although agriculture is successful in many areas across the country, it is predominantly associated with the Prairies and Mixedwood Plains ecozones (Fig. II.3; Table II.1).

Some of Canada's ecozones are shared with other countries. For example, the seemingly small Prairies ecozone (450 000 km^2) is, in fact, only the northern tip of a unit that reaches well into the heartland of the United States. This ecozone also forms part of the world's set of temperate grasslands. Similarly, Canada's

Figure II.2

Marine and terrestrial ecozones in Canada



Source: State of the Environment Directorate, Environment Canada.

Arctic ecozones form a vital segment — about 20% — of the world's total Arctic ecosystems.

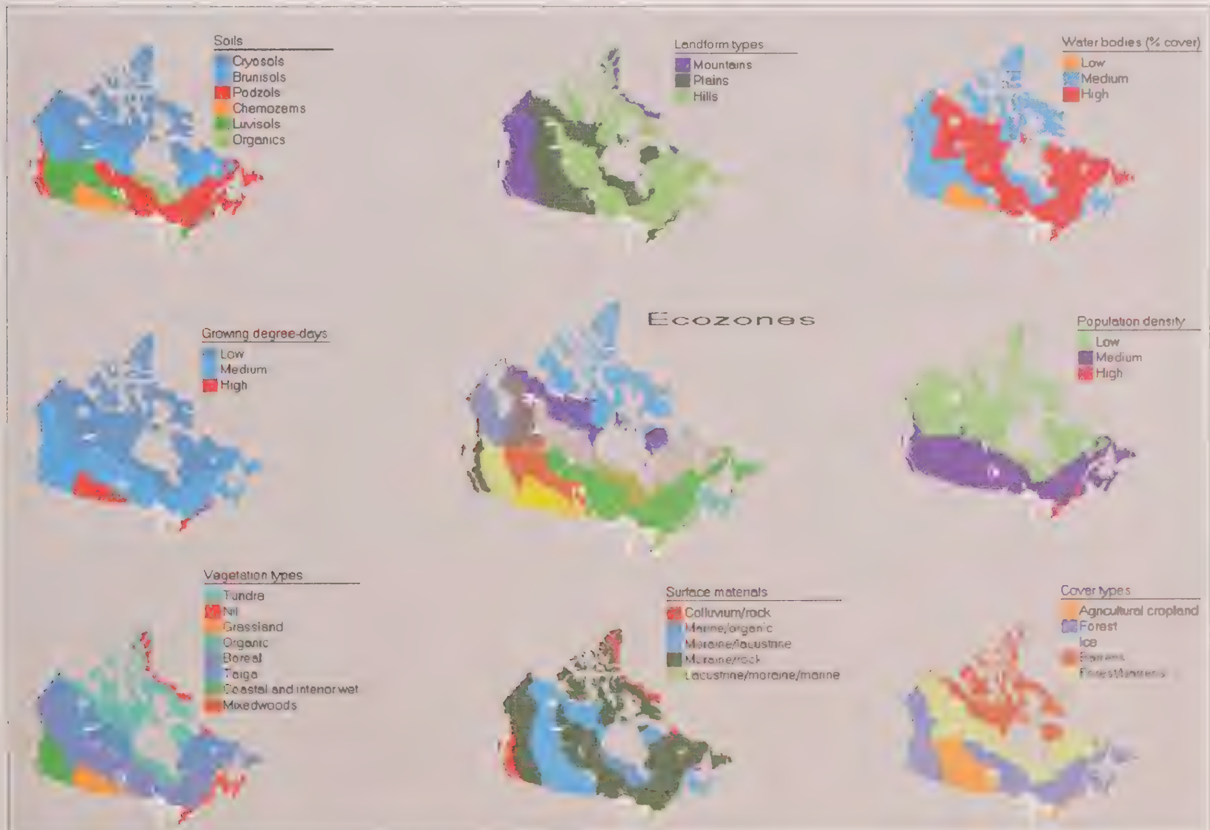
The vast majority of Canada's population is located in the southern fringe of the country, concentrated in four of the smallest ecozones. Despite sharp ecological contrasts, the Pacific Maritime, Prairies, Mixedwood Plains, and Atlantic Maritime ecozones have this one characteristic in common — they have been highly influenced by human activities. While it is hardly surprising that the area associated with the Mixedwood Plains ecozone (the ecozone that includes the heavily built-up area from Windsor to Montreal) has the highest percentage of urban dwellers, it is perhaps surprising that the Prairies ecozone has the third highest and also has the second largest proportion of people in Canada (Table II.2). Human-modified systems constitute much of the Prairies and Mixedwood Plains ecozones. Settlement patterns and resource exploitation activities have transformed these ecozones, and they are unlikely ever to return to a more native state.

Figure II.4 presents Canada's ecozones somewhat differently, this time with the terrestrial and marine ecozones arranged into seven units. The intent of organizing them this way was to provide a slightly more familiar presentation for reporting purposes. Some of the ecozones roughly coincide with particular provinces and territories and so were grouped on that basis. For instance, the five ecozones mainly associated with British Columbia and the Yukon (Taiga Cordillera, Pacific Maritime, Montane Cordillera, Boreal Cordillera, and Pacific Marine) have been grouped as Pacific and Western Mountains. Similarly, the Prairies and the Boreal Plains ecozones are linked to the Prairie provinces and have been grouped as Central Plains. In other cases, such as the Boreal Shield ecozone, there was no particular coincidence.

Presenting the ecozones in this way is useful, as it tends to draw attention to Canada's political boundaries. The provinces

Figure II.3

Prevalent attributes of Canada's terrestrial ecozones



Source: State of the Environment Directorate, Environment Canada

Table II.1

Some descriptive biophysical characteristics of Canada's marine and terrestrial ecozones

Ecozone	Landforms	Surface materials/ soils	Climate/ oceanographic characteristics	Vegetation/ productivity	Wildlife (mammals/birds)	Human activities	Main communities
Marine ecozones							
Pacific	Pacific Ocean basin and narrow continental shelf; numerous fjords	Generally ice-free except for local pockets of landfast ice (seasonal)	General eastward-setting oceanic current (Subarctic Current) with divergence point off the shelf; pronounced seasonal upwelling in the south; El Niño influences	One of Canada's most productive oceanic areas	Important seasonal migrations of animals between neritic and oceanic areas; important commercial species include oyster, shrimp, five species of salmon, herring, Pacific Hake, Sablefish, Pacific Halibut, clams, Dungeness Crab, rockfish, and flatfish species	Fishing, tourism	
Arctic Archipelago	Limited to "shelf-type" depths; high Arctic islands, Arctic and Hudson Bay coasts; much is rocky coastline, numerous channels and straits; high coastal relief in east, low in south and west	Seasonal ice; open water 2–3 months in summer	Relatively high freshwater input along northern continental boundary	Higher productivity and abundance of life than permanent ice area	Intense summer migration into region, generally following the ice edge retreat; locally high concentrations of marine birds and mammals, including Beluga, Walrus, seals; Polar Bear	Oil and gas, limited fishing and hunting	
Arctic Basin	Limited to the most northern polar cap areas	Mainly permanent pack ice	Affected by easterly winds driving a clockwise circumpolar gyre in basin; no land components	Low biological productivity and diversity	Polar Bear and seals dominate mammals	Few, if any, activities	
Northwest Atlantic	Primarily continental shelf; generally low coastal relief	Seasonal ice area	Labrador Current exerts strong influence both on shelf and offshore (lower-salinity cold water)	Strongly influenced by the Labrador Current and Arctic waters	Subarctic species in north to boreal species in south; important commercial species include oyster, shrimp, Snow Crab, haddock, hake, Pollock, American Plaice, codfish, halibut, flounder, herring, mackerel, Capelin, and Atlantic Salmon	Fishing, tourism	
Atlantic	Large southern shelf areas (Grand Banks, Scotian Shelf) as well as the Northwest Atlantic Ocean basin	Generally ice-free except for local pockets of landfast ice and some years of seasonal ice	Includes mostly temperate water masses originating from the south; Gulf Stream offshore and Slope Water Current at the shelf break; mixing zone between cold, lower-salinity water from the north and warmer water from the south	A very productive area for many species	Includes both neritic and oceanic species; important commercial ground fisheries occur on shelves; important commercial species include lobster, scallop, codfish, haddock, hake, Pollock, redfish, halibut, mackerel, and Atlantic Salmon	Fishing, tourism	
Terrestrial ecozones							
Arctic Cordillera	Mountains	Ice, snow, colluvium, rock/Cryosols	Extremely cold, dry; continuous permafrost	Mainly unvegetated; some shrub–herb tundra	Polar Bear (along coast), Arctic Hare; Northern Fulmar, Common Ringed Plover, Snow Bunting	Hunting, tourism	Pond Inlet, Clyde River, Broughton Island
Northern Arctic	Plains, hills	Moraine, rock, marine/Cryosols	Very cold, dry; continuous permafrost	Herb–lichen tundra	Peary Caribou, Muskox, Wolf, Arctic Hare; Red-throated Loon, Brant, ptarmigan, Greater Snow Goose	Hunting, tourism/ recreation, some mining	Iqaluit, Cambridge Bay, Holman, Arctic Bay, Taloyoak, Pangnirtung, Sachs Harbour, Cape Dorset, Resolute, Igloolik
Southern Arctic	Plains, hills	Moraine, rock, marine/Cryosols	Cold, dry; continuous permafrost	Shrub–herb tundra	Barren-ground Caribou, Wolf, Grizzly Bear, Arctic Fox, Arctic Ground Squirrel, lemming; Arctic Loon, ptarmigan, Snowy Owl	Hunting, trapping, tourism/ recreation, mineral development	Tuktoyaktuk, Rankin Inlet, Arviat, Paulatuk, Povungnituk

continued on next page

Table II.1 (continued)

Some descriptive biophysical characteristics of Canada's marine and terrestrial ecozones

Ecozone	Landforms	Surface materials/ soils	Climate/ oceanographic characteristics	Vegetation/ productivity	Wildlife (mammals/birds)	Human activities	Main communities
Terrestrial ecozones (cont'd)							
Taiga Plains	Plains, some foothills	Organic, moraine, lacustrine/Cryosols, Brunisols	Cold, semiarid to moist; discontinuous permafrost	Open to closed mixed evergreen–deciduous forest	Moose, Woodland Caribou, Wood Bison, Wolf, Black Bear, Red Squirrel, Northern Shrike, Spruce Grouse	Hunting, trapping, tourism/ recreation, oil and gas development, marginal agriculture in south	Inuvik, Fort Simpson, Wrigley, Norman Wells, Aklavik, Hay River, Fort McPherson
Taiga Shield	Plains, some hills	Canadian Shield rock, moraine/ Cryosols, Brunisols	Cold, moist to semi-arid; discontinuous permafrost	Open evergreen–deciduous trees; some lichen–shrub tundra	Moose, Barren-ground Caribou, Wolf, Snowshoe Hare, Red Squirrel; Red-necked Phalarope, Northern Shrike	Tourism/recreation, some mining, some hunting and trapping	Yellowknife, Goose Bay, Uranium City, Churchill Falls, Happy Valley, Kuujjuarapik
Taiga Cordillera	Mountains	Colluvium, moraine, rock/Cryosols, Gleysols, Brunisols	Cold, semiarid; discontinuous permafrost	Shrub–herb–moss–lichen tundra	Dall's Sheep, Grant's Caribou, Black Bear, Grizzly Bear; Peregrine Falcon, ptarmigan	Trapping, hunting, mining, tourism/recreation, oil and gas	Old Crow
Hudson Plains	Plains	Organic, marine/ Cryosols	Cold to mild, semiarid; discontinuous permafrost	Wetland, some herb–moss–lichen tundra, evergreen forest	Woodland Caribou, Moose, Black Bear, marten, Arctic Fox; Canada Goose	Hunting, trapping, recreation	Churchill, Moosonee, Attawapiskat
Boreal Plains	Plains, some foothills	Moraine, lacustrine organic/Luvisols, Brunisols	Cold, moist	Mixed evergreen–deciduous forest	Woodland Caribou, Mule Deer, Moose, Black Bear, beaver, Muskrat; Boreal Owl, Blue Jay	Forestry, agriculture, tourism/recreation, oil and gas development	La Ronge, The Pas, Flin Flon, Peace River, Fort Smith, Fort Vermilion, Hinton
Boreal Shield	Plains, some hills	Canadian Shield rock, moraine, lacustrine/Podzols, Brunisols	Cold, moist	Evergreen forest, mixed evergreen–deciduous forest	White-tailed Deer, Moose, Black Bear, Canada Lynx, marten, Red Squirrel, Boreal Owl, Blue Jay	Forestry, mining, tourism/recreation, hunting, trapping	Thunder Bay, St John's, Sudbury, Sault Ste. Marie, Chicoutimi, North Bay, Sept-Îles, Gander, Thompson
Boreal Cordillera	Mountains, some hills	Colluvium, moraine, rock/Brunisols, Podzols, Cryosols	Moderately cold, moist	Largely evergreen forest; some tundra, open woodland	Moose, Dall's Sheep, Grizzly Bear, Black Bear; ptarmigan, Spruce Grouse	Hunting, trapping, forestry, tourism/recreation, mining	Whitehorse, Dawson, Faro, Teslin, Haines Junction, Mayo Landing
Pacific Maritime	Mountains, minor coastal plains	Colluvium, moraine, rock/Podzols, Brunisols	Mild, temperate, very wet to cold alpine	Coastal evergreen forest	Black Bear, Grizzly Bear, Mountain Lion; Black Oystercatcher, Tufted Puffin	Forestry, fish processing, urbanization, agriculture	Vancouver, Victoria, Prince Rupert, Nanaimo, Port Alberni, Chilliwack
Montane Cordillera	Mountains and interior plains	Moraine, colluvium, rock/Luvisols, Brunisols	Moderately cold, moist to arid	Evergreen forest, alpine tundra, interior grassland	Woodland Caribou, Mule Deer, Moose, North American Elk, Mountain Goat, Blue Grouse, Steller's Jay	Forestry, agriculture, tourism/ recreation	Prince George, Kelowna, Kamloops, Williams Lake, Vernon, Penticton, Nelson, Trail, Cranbrook, Quesnel
Prairies	Plains, some hills	Moraine, lacustrine/ Chernozems	Cold, semiarid	Grass; scattered deciduous forest ("aspen parkland")	Mule Deer, White-tailed Deer, Pronghorn, Coyote, Prairie Dog, Sage Grouse, Burrowing Owl	Agriculture, urbanization recreation, oil and gas development	Calgary, Winnipeg, Edmonton, Regina, Saskatoon, Lethbridge, Red Deer, Prince Albert, Brandon
Atlantic Maritime	Hills and coastal plains	Moraine, colluvium, marine/Brunisols, Podzols, Luvisols	Cool, wet	Mixed deciduous–evergreen forest	White-tailed Deer, Moose, Black Bear, Coyote, Raccoon, Blue Jay, Eastern Bluebird	Forestry, agriculture, fish processing, tourism/ recreation	Halifax, Saint John, Dartmouth, Charlottetown, Moncton, Sydney, Rimouski, Sherbrooke
Mixedwood Plains	Plains, some hills	Moraine, marine, rock/Luvisols, Brunisols	Cool to mild, moist	Mixed deciduous–evergreen forest	White-tailed Deer, Red Fox, Raccoon, Striped Skunk, beaver, Grey Squirrel, Great Blue Heron, Blue Jay	Agriculture, urbanization, tourism/recreation	Toronto, Montreal, Windsor, Hamilton, Quebec, Ottawa, London, Mississauga

Source: Wiken (1986), State of the Environment Directorate, Environment Canada, Marine Environmental Quality Advisory Group (1994), Ecological Stratification Working Group (1996)

and territories have substantial jurisdictional responsibilities and take on many specific activities related to monitoring, planning, and sustainability. This ecozone arrangement has been used to organize the chapters in Part II of this report.

Building a Capacity to Think, Plan, and Act in Terms of Ecosystems

An ecosystem approach to understanding ecological change and developing appropriate responses requires a fundamental shift in thinking. Just as important, a more informative knowledge base for understanding ecosystems and designing plans must be created. Once this knowledge base is in place, the results of actions and the ongoing condition of ecosystems have to be monitored.

Governments and other groups cannot afford to start from scratch in building an ecosystem information base. An unprecedented degree of coordination is necessary at all levels to make full use of existing information and capabilities. The starting point is a patchwork of information holdings throughout the country, many of which relate only to specific environmental components, geographical areas, or time periods. Environmental and socioeconomic data have usually been collected independently by various agencies for different purposes.

A comprehensive ecosystem perspective needs to be built using existing expertise, information holdings, and monitoring networks. The ecozone maps and the characterization and integrated analysis of ecozones are innovative and vital parts of this work. Ecozones provide a general picture of the wealth and diversity of Canada's ecosystems. The strength of the reports and assessments at the ecozone level relies substantially on information that has been integrated at a more detailed level. A federal, provincial, and territorial initiative recently refined the mapping and descriptions of the ecozone subunits, such as the 217 ecoregions and 1 030 ecodistricts (Ecological Stratification Working Group 1996). Various government departments and agencies and other organizations have integrated their national information sets within the ecozone and ecoregion frameworks. This integration of data has already improved the quality of environmental information available to policy- and decision-makers.

Chapters 3–9 of this report describe the current state of Canadian ecozones. The intent of these chapters is to provide a national overview according to ecozone groupings and individual ecozones. Condi-

Table II.2

Some quantitative environmental and socioeconomic characteristics of Canada's terrestrial ecozones

		Area					Population (1991)					
		Land		Fresh water			Canada			Urban areas		
Ecozone groupings[a]	Total area (% of Canada)	Area (km²)	% of Canada's total area	Area (km²)	% of Canada's total area	Dominant cover type	No. of people	% of total Canadian population	Density (no. of people/ 100 km²)	No. of people	% of total ecozone population	GDP 1991 ($ millions)
Arctic												
Arctic Cordillera	2.5	230 873	2.3	19 717	0.2	Perennial snow/ice	1 047	<0.01	0.5	0	0.0	12
Northern Arctic	15.2	1 361 433	13.7	149 447	1.5	Barren lands	16 328	0.06	1.2	3 450	21.1	379
Southern Arctic	8.3	773 041	7.8	59 349	0.6	Arctic/alpine tundra	10 314	0.04	1.3	0	0.0	150
Taiga												
Taiga Plains	6.5	580 139	5.8	66 861	0.7	Coniferous forest	21 429	0.08	3.7	9 651	45.0	532
Taiga Shield	13.7	1 253 887	12.6	112 513	1.1	Transitional forest	33 589	0.12	2.7	11 860	35.3	1 145
Hudson Plains	3.6	353 364	3.5	8 996	0.1	Transitional forest	9 938	0.04	2.8	1 003	10.1	115
Boreal												
Boreal Shield	19.5	1 782 252	17.9	164 118	1.6	Coniferous forest	2 831 824	10.37	158.9	1 694 777	59.8	49 005
Atlantic												
Atlantic Maritime	2.0	183 978	1.8	19 772	0.2	Mixed forest	2 510 203	9.20	1 364.4	1 235 588	49.2	39 925
Great Lakes–St. Lawrence												
Mixedwood Plains	2.0	138 421	1.4	56 009	0.6	Agricultural cropland	14 016 101	51.35	10 125.7	11 887 793	84.8	325 199
Central Plains												
Boreal Plains	7.4	679 969	6.8	57 831	0.6	Coniferous forest	707 695	2.59	104.1	299 019	42.3	13 744
Prairies	4.8	469 681	4.7	8 429	0.1	Agricultural cropland	3 851 089	14.11	819.9	3 120 032	81.0	90 756
Pacific and Western Mountains												
Taiga Cordillera	2.7	264 480	2.7	360	<0.1	Coniferous forest	309	<0.01	0.1	0	0.0	5
Boreal Cordillera	4.7	459 680	4.6	4 920	<0.1	Coniferous forest	30 839	0.11	6.7	16 335	53.0	946
Pacific Maritime	2.2	205 175	2.1	13 805	0.1	Coniferous forest	2 504 393	9.17	1 220.6	2 174 948	86.8	58 152
Montane Cordillera	4.9	479 057	4.8	13 053	0.1	Coniferous forest	751 761	2.75	156.9	452 418	60.2	14 035
Canadian total	100.0	9 215 430	92.4	755 180	7.5		27 296 859	100.00	296.2	20 906 874	76.6	594 100

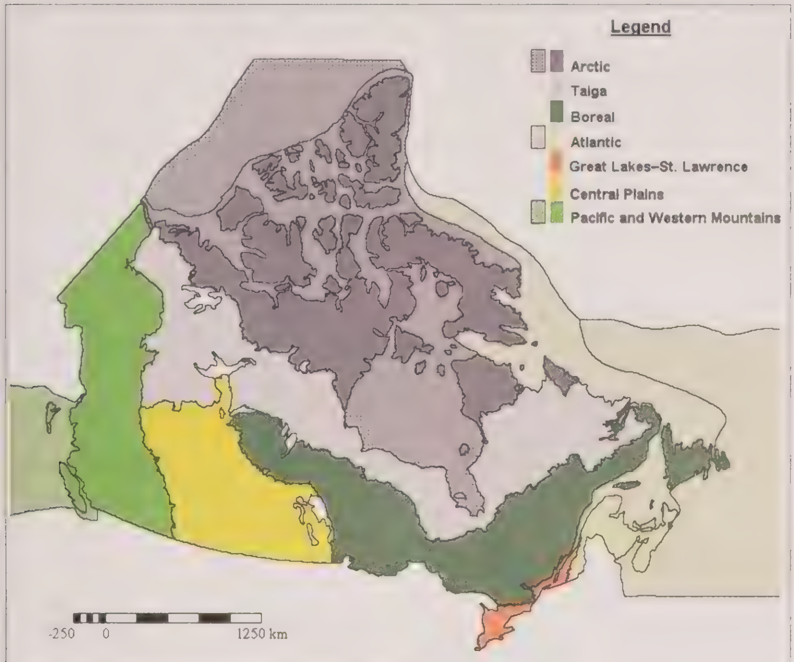
Note: Percentages may not add up owing to rounding.

[a] Marine ecozones are not listed.

Source: State of the Environment Directorate, Environment Canada.

Figure II.4

Areas covered by the seven groups of ecozones used for reporting purposes



Source: State of the Environment Directorate, Environment Canada

tions and trends as well as the key issues associated with each major ecozone are described. More detailed material is available from provincial state of the environment reports, technical reports, and other sources.

Much more work will be needed to support an ecosystem perspective. The ecosystem approach requires integrating environmental information with social and economic information. These factors do not occur in isolation within a geographical area but rather interact continuously. Looking to the future, the formal integration of environmental and socioeconomic data will be the next challenging step in the evolution of an ecosystem approach to sustainable development issues.

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Chapter 3 Pacific and Western Mountains Ecozones

Highlights

The five Pacific and Western Mountains ecozones (four terrestrial: Pacific Maritime, Montane Cordillera, Boreal Cordillera, and Taiga Cordillera; and one marine: Pacific Marine) coincide roughly with British Columbia and the Yukon. Although these ecozones are rich in wild fauna, flora, and ecosystems, some parts of them — particularly in the Pacific Maritime ecozone — are heavily stressed by rapid population growth, urban development, and resource-based industries, such as forestry.

■

Between 1990 and 1995, substantial progress was made in establishing protected areas in the four terrestrial ecozones. Currently, there are more than 800 protected areas encompassing 14 million hectares; 85% of these areas are strictly protected (e.g., national parks and ecological reserves). In the marine ecozone, progress in conferring any form of legal protection has been modest: there are 290 000 km^2 of Canadian marine waters and 6 500 coastal islets off the B.C. coast, but only 4 946 km^2 had protected status in 1995.

■

The coastal temperate rain forest covers more than 10 million hectares, and some of its ecosystems have the highest biomass per hectare found on Earth. Some 2.2 million hectares of this rain forest have been logged over the past 120 years. In early 1995, 52% of the major forest cover comprised trees older than 140 years, and 8.4% (900 000 ha) of the forest had protected status.

■

Since 1920, logging has been increasing in importance as a forest disturbance. Between 1920 and 1992, while the area logged each year doubled in the rest of Canada, it tripled in the Pacific Maritime ecozone and increased 15-fold in the Montane Cordillera ecozone.

■

Most salmon stocks in the Pacific Marine ecozone are in relatively good condition; Sockeye, Pink, and Chum salmon have increased coastwide since the 1960s. In the Fraser River (despite recent journalistic references to "missing sockeye"), numbers of these three species are close to historic highs. However, Chinook and Coho salmon stocks are depressed, owing to overfishing, habitat damage, and natural factors. Although many Chinook stocks are responding well to rebuilding efforts, declines in Coho stocks persist and have been the focus of a major rebuilding program. In the Yukon River, which flows through Alaska to the Bering Sea, Chinook and Chum salmon stocks are stable but low in abundance.

■

As of February 1995, contamination by toxic substances such as dioxins and furans had caused the closing of 120 200 ha of coastal marine habitat to commercial and recreational shellfish harvesting — up from almost 90 000 ha in May 1992 and 113 700 in August 1993. The increases, however, primarily reflect expanded sampling rather than increased contaminant levels. In fact, declining levels of dioxins and furans permitted the reopening of 48 650 ha of shellfish habitat in August 1995.

■

Between 1991 and 1994, the average discharge of organochlorine compounds from B.C. pulp mills was reduced by 56%.

■

Organochlorines such as toxaphene, DDT, and PCBs have been found in remote areas of the Boreal Cordillera and Taiga Cordillera ecozones. The main source is long-range atmospheric transport from other parts of the world. Consumption advisories based on toxaphene have been issued for Burbot livers and Lake Trout flesh from Lake Laberge and for Burbot livers from Atlin Lake.

■

Within the four terrestrial ecozones, 24 species are known to be extirpated or extinct. In the marine ecozone, of 70 species or groups of species for which long-term data are available, about 30% are at historic lows. Overall, within the five ecozones, 65 species are listed as vulnerable, threatened, or endangered — about half of which are found in the Montane Cordillera ecozone.

■

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For millions of years, powerful natural forces have shaped the environment of western and northwestern Canada. Nevertheless, this is still a relatively young, angular, and irregular land, and these ancient natural forces continue to exert a considerable influence on its evolution. Each year, floods, landslides, and avalanches, along with less catastrophic natural processes, create and modify ecosystems throughout the region. Cataclysmic change is also a constant possibility. Earthquakes are not uncommon, and volcanoes have been active in the very recent geological past (Box 3.1). Added to these are the effects of numerous human activities, seemingly insignificant as individual acts but often profound in their cumulative impact.

Box 3.1
Ancient forces ... still at work

Earthquakes are common in the western mountains, especially on the ocean floor off the Queen Charlotte Islands and Vancouver Island, in and adjacent to the Strait of Georgia, and in the St. Elias and Mackenzie mountains. Much of the seismic activity is closely associated with the interactions of lithospheric plates in the northeast Pacific Ocean. Although most earthquakes are small and cause no damage, two quakes greater than Richter magnitude 6.5 occur in western Canada every decade, on average (Whitham and Hasegawa 1975), with potential for earthquake damage and some loss of life. The greatest hazard from destructive earthquakes is in south coastal British Columbia, because it is here that most of the region's population is located.

Geological evidence shows that large seismic sea waves, known as tsunamis, have struck the west side of Vancouver Island many times in the past, apparently triggered by submarine earthquakes. The most significant recent tsunami was generated by the Alaska earthquake in 1964 and resulted in damage to 260 homes in Port Alberni on Vancouver Island. Between 1900 and 1970, 170 tsunamis were recorded, and 35 caused damage near their sources. Only nine caused widespread destruction, and even fewer produced significant wave run-ups on B.C. shores.

There have been scores of volcanic eruptions in the Western Cordilleras. Most have been small, but a few large volcanoes have erupted in these ecozones, with the most recent being just south of Beaver Creek, Yukon, near the Alaska–Yukon boundary, about 1 200 years ago. Although there have been no eruptions during this century, one lava flow near the Alaska–British Columbia boundary just east of Stewart, B.C., is probably less than 200 years old (Souther 1977). To the south, in northwestern Washington state, Mt. Baker last erupted in 1972, while Mt. St. Helens erupted in 1980.

Five ecozones

The dominant and unifying feature of this region is the rugged mountain landscape, but differences in relief, climate, vegetation, and other ecological characteristics also create considerable diversity. The region, in fact, contains five distinct ecozones (Fig. 3.1a). Four of these are terrestrial — the Taiga Cordillera, Boreal Cordillera, Montane Cordillera, and Pacific Maritime ecozones. Embracing 1 364 000 km^2 and covering nearly 14% of Canada's land area, they take in most of the Yukon and British Columbia as well as a narrow fringe along the southwestern border of Alberta and a small portion of the Northwest Territories. The fifth — the Pacific Marine ecozone — includes the Canadian portion of the Pacific Ocean.

Figure 3.1a
Ecozones of the Pacific and Western Mountains

Source: State of the Environment Directorate, Environment Canada

Covering most of the northern half of the Yukon and the southeastern corner of the Northwest Territories, the *Taiga Cordillera* is a sparsely populated ecozone of 251 000 km^2. Much of it is underlain by permafrost, with about half of the vegetative cover characterized by alpine sedges, shrubs, or grasses. Transitional forests occur between the open tundra and closed forest. These consist of open White and Black spruce mixed with patchily distributed dwarf birches and willows. Closed boreal coniferous forests are found in the mountains of the northeastern Yukon. Much of the range of the Porcupine Caribou herd occurs within this ecozone.

Immediately to the south and west lies the *Boreal Cordillera* ecozone. Consisting of extensive mountains and plateaus separated by wide valleys and lowlands, it spans 444 000 km^2, occupying almost all of southern Yukon and the northern half of British Columbia. Black and White spruce and Tamarack dominate, although stands containing Subalpine Fir and Lodgepole Pine are not uncommon. There are also extensive areas of rolling alpine tundra. In some parts of this ecozone, there are grasslands on south-facing slopes with boreal forest vegetation on the north-facing slope, a feature unique within the boreal forests of Canada.

The 473 000 km^2 of the *Montane Cordillera* ecozone stretch southeast from north-central British Columbia all the way to the southwestern corner of Alberta. It is the most diverse of all of Canada's 15 terrestrial ecozones, containing some of the driest, wettest, coldest, and hottest conditions found in the country. The ecosystems are variable, ranging from alpine tundra to dense conifer forests to dry

sagebrush and grasslands. Wetlands and small lakes dot the landscape, but there are also some large, deep lakes and major river systems, including the Fraser River and the Columbia River headwaters.

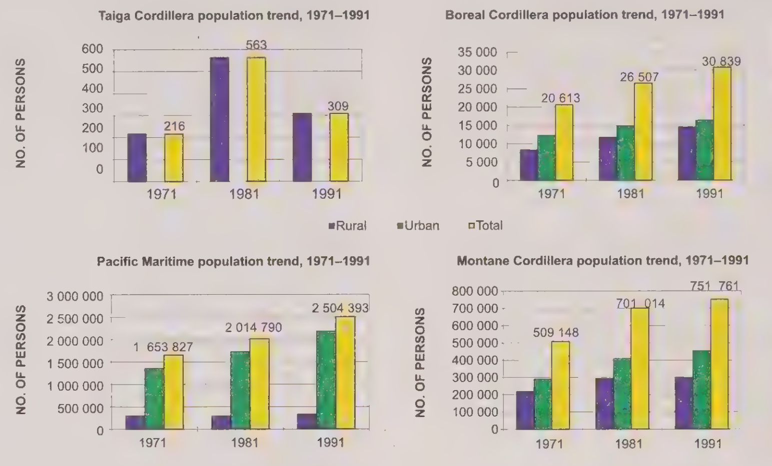
The *Pacific Maritime* ecozone covers 195 000 km² and extends along the B.C. coast, taking in the Coast Mountains and British Columbia's marine islands as well as a small corner of southwestern Yukon. The climate is moist and tempered by the ocean. Exposed and windward areas with high rainfall and no pronounced summer dry period are dominated by temperate rain forest of Western Hemlock, Western Red Cedar, and Sitka Spruce, which can reach very large dimensions and may grow to great ages. Such forests comprise the ancient or "old-growth" forests of this ecozone. In drier, rain shadow areas, where fire has played an important ecological role, the vegetation consists primarily of second-growth temperate forests dominated by Douglas-fir, subalpine stands of Mountain Hemlock and Pacific Silver Fir in the high-elevation, snowpack forests, and alpine tundra on the mountain summits. With moderate temperatures and a dry rain shadow climate, the Gulf Islands and adjacent lands include such semi-Mediterranean ecological features as arbutus and Garry Oak woodlands.

The *Pacific Marine* ecozone includes all of Canada's Pacific coastal waters as far north as the Bering Sea. In large part, sea ice is absent; seasonal ice does, however, occur in sheltered bays and inlets, particularly those with freshwater discharges. Between the southern tip of Vancouver Island and Dixon Entrance in the north, ocean surface temperature declines about 3°C. At any latitude within this ecozone, oceanic surface water temperatures vary seasonally by approximately 7°C, a variation to which its biological community must adapt.

This ecozone is of particular importance to feeding, staging, and overwintering waterfowl, seabirds, and shorebirds. All of the B.C. breeding population of Brandt's Cormorants occurs on the west coast of Vancouver Island. Overall, this ecozone provides habitat for approximately 4 500

Figure 3.1b

Population trends, 1971–1991



Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada, based on the 1991 Census. For further details, see Endnotes.

documented species of marine invertebrates, making up a major portion (88%) of all marine animals in the ecozone (Lambert 1994). Pacific Salmon, Pacific Herring, Pacific Halibut, other fish, and marine invertebrates form the commercial fishery.

People and lifestyles

The human impact on the environment is the product of population, lifestyle, and economic activity. Generally speaking, the larger the population, the more consumptive its lifestyle, and the more industrialized its economy, the greater its impact on the environment. The mix of these factors and their resulting environmental consequences vary considerably from one ecozone to another.

Population

Of the 3.25 million people who inhabit these ecozones, a mere 300, according to the 1991 census, make their homes in the Taiga Cordillera (Statistics Canada 1992). These are the Vuntut Gwitchin people (the people "of the lakes"), who live mainly in Old Crow, the most northern community in the Yukon. The population in the Boreal Cordillera ecozone is considerably greater but still numbered only about 30 000 in 1991, with more than half living in urban communities such as Whitehorse, Watson Lake, and Faro. Human numbers increase dramatically, however, in the southern portions of the Montane Cordillera and Pacific Maritime ecozones, which recorded 750 000 and 2.5 million people, respectively, in 1991 (see Fig. 3.1b).

About 75% of British Columbians live in the Pacific Maritime ecozone. Most of them are concentrated in the Georgia Basin, the area that embraces the large urban centres of the Lower Mainland and Victoria. Over the past 20 years, British Columbia's population has expanded rapidly, largely as a result of immigration, with approximately half of the newcomers arriving from other parts of Canada and half from abroad. Between 1971 and 1986, the Georgia Basin absorbed about 69% of this growth, or nearly half a million people. Almost two-thirds of this increase occurred in the Lower Mainland and one-quarter on southeastern Vancouver Island. The rest is accounted for by the Gulf Islands, where the population grew by an astonishing 58% over the 15-year period.

High rates of population growth in the basin are expected to continue. Over the

Figure 3.1c
Population change in selected centres, 1971–1991

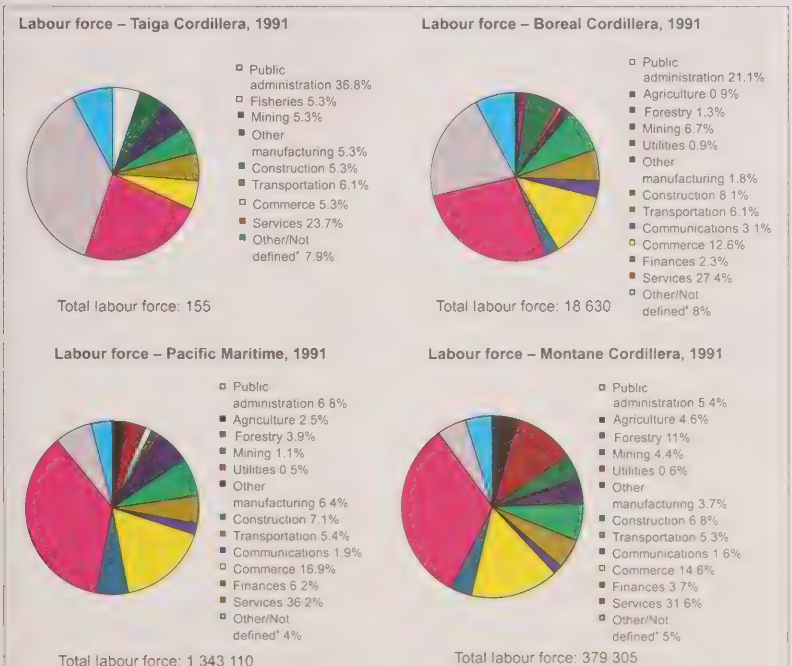
Selected centres	Population 1971	Population 1991	Population % change
Old Crow, Y.T.	NA	256	NA
Dawson, Y.T.	762	972	28
Whitehorse, Y.T.	11 217	17 925	60
Watson Lake, Y.T.	553	912	65
Prince Rupert, B.C.	15 747	16 620	6
Prince George, B.C.	49 100	69 653	42
Port Hardy, B.C.	1 761	5 082	189
Kamloops, B.C.	43 790	67 856	55
Banff, Alta.	NA	5 688	NA
Vancouver[a], B.C.	1 082 352	1 602 502	48
Victoria[a], B.C.	195 800	287 897	47
Cranbrook, B.C.	12 000	16 447	37

Note: NA = not available.

[a] The geographic extent of a Census Metropolitan Area in 1971 may not correspond to that for 1991. For further details, see Endnotes.

Source: Statistics Canada (1972, 1992, 1994).

Figure 3.1d
Labour force composition, 1991



Note: Using the 1970 Standard Industrial Classification, the four primary sectors have been grouped with their respective first-stage resource processing industries. For further details, see Endnotes.

* "Other Not defined" represents labour force categories that were less than 0.5% of the total labour force as well as responses for which the respondent did not specify the industrial category in which he/she or other household members were employed.

Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada, based on the 1991 Census.

next quarter century, the populations of both the Greater Vancouver Regional District and Victoria are projected to grow by about 40% (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993).

The Montane Cordillera ecozone is much less densely urbanized; nevertheless, more than half of its population lives in towns and cities such as Kelowna, Kamloops, Penticton, and other smaller centres. These communities have also attracted a large share of newcomers. The population in the Okanagan Valley alone has increased by 45% over the past 20 years. The urbanization trend is also evident in the Boreal Cordillera ecozone. Between 1951 and 1991, Whitehorse's share of the ecozone's population increased from 29% to 65%.

Lifestyles

The environmental impact of these growing urban populations, especially in the south, is compounded by lifestyles based on high levels of consumption. In fact, British Columbians use more resources per person than the inhabitants of any other country outside Canada, except the United States (B.C. Round Table on the Environment and the Economy 1994).

Economic activity

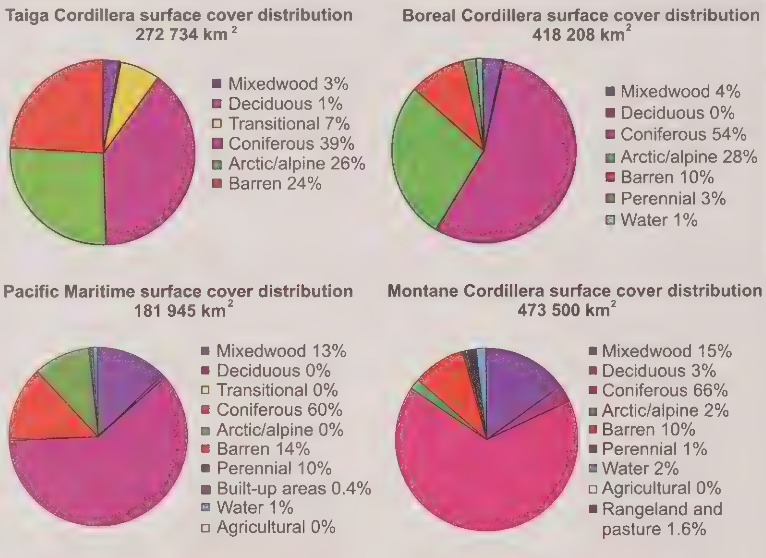
The impact of economic activity on these ecozones also differs greatly between north and south, but one common factor runs through the economies of all these ecozones: the importance of activities, such as resource exploitation, tourism, and recreation, that are directly dependent on the environment. The resource sector, which includes industries such as farming, ranching, mining, logging, and fishing, is particularly important. In British Columbia, it accounts directly for about 19% of the province's gross domestic product and directly and indirectly for 22% of its jobs (B.C. Ministry of Finance and Corporate Relations 1994). Resource extraction and processing industries often have a substantial impact on the environment, and, not surprisingly, they are involved in many of the big environmental issues affecting these regions.

Figure 3.1e
Characteristics of the Pacific Marine ecozone

Surface temperature (°C), August	Presence of sea ice	Tidal range (m)
8–14, 20 in sheltered areas	Absent year-round	2.5–4.0

Source: Adapted from Department of Canadian Heritage (1995).

Figure 3.1f
Land cover distribution



Source: National Oceanic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR) imagery; Manitoba Remote Sensing Centre, Manitoba Department of Natural Resources.

Cheap energy, especially hydroelectricity, has been an important contributor to industrial growth, but it has also encouraged the establishment of energy-intensive industries such as pulp and paper manufacturing and metal production. Industries consume approximately half of the energy used in the western ecozones (Fig. 3.2), predominantly in the Pacific Maritime and Montane Cordillera. Energy production and use have a wide variety of environmental impacts, ranging from habitat destruction by hydro dams to air pollution from fossil fuel combustion.

The Pacific Maritime and Montane Cordillera ecozones are also the centre of most resource-based activities, although they support a large manufacturing and service economy as well. In the Boreal Cordillera ecozone, gold and base metal mining has been the major industrial activity, although forestry is now increasing. In 1994, there were about 250 active gold placer mines in the ecozone. Plans are also under way to reopen the lead–zinc mine at Faro. At the moment, industrial resource exploitation in the Taiga Cordillera is limited to mineral exploration, but the Gwitchin people harvest local resources for many of their needs. The Porcupine Caribou herd is an important source of meat and hides; fish, muskrat, and other "country foods" are also major elements in their diet. Fishing, another resource industry, is the main economic activity in the Pacific Marine ecozone, along with shipping and recreation.

Over the past decade, some shifts in labour force patterns have occurred in all of these ecozones (Fig. 3.3). Most have been minor, except for the very rapid growth of the service sector. Because service jobs are largely urban based, the increase in this sector is closely connected to urban population growth in these regions.

Ecozone linkages
Ecozones are not physically, biologically, economically, or culturally self-contained. Economic activity in one ecozone, for example, may depend on resources from another. The environmental consequences of that activity may also affect ecozones other than the one in which it takes place. These relationships are evident even in the most isolated of these areas, the Taiga Cordillera. The Gwitchin people of Old Crow are self-sufficient in many respects but nevertheless rely on the outside world for essential goods and services that have to be brought in by air. Although remote from any major source of industrial activity, the Taiga Cordillera is also exposed to toxic metals and chemicals carried in by atmospheric currents from the industrial cities and farmlands of North America and elsewhere. There are serious concerns about the accumulation of these substances in plants and animals consumed by local residents.

In contrast, the Pacific Maritime ecozone, particularly the Georgia Basin, must draw much more heavily on other ecozones for resources to fuel its industries and goods to meet the needs of its many inhabitants. In turn, many of the wastes and pollutants it produces may eventually be the cause of environmental problems elsewhere. Compared with the Taiga Cordillera, the Georgia Basin has a much larger ecological footprint, one that extends far beyond its own boundaries.

Ecological impacts
The combined pressure of rapidly expanding populations, high-consumption lifestyles, and an energy-intensive, highly industrialized economy has brought a

Figure 3.1g

Air temperature, degree-days, and precipitation in selected centres

	Air temperature (°C)				Degree-days[a]		Precipitation			
Selected centres	Mean January maximum	Mean January minimum	Mean July maximum	Mean July minimum	Heating (<18°C)	Growing (>5°C)	Mean annual rainfall (mm)	Mean annual snowfall (cm)	Mean total precipitation (mm)	Days with measurable precipitation
Old Crow, Y.T.	NA	–36.7	NA	8.1	NA	NA	130	117	248	NA
Dawson, Y.T.	–27.4	–34.6	22.6	8.9	8 415	1 016	181	153	313	132
Whitehorse, Y.T.	–14.4	–23.2	22.6	7.6	6 947	872	160	145	269	NA
Watson Lake, Y.T.	–19.4	–30.0	21.1	8.7	7 725	956	257	219	414	152
Prince Rupert, B.C.	4.1	–2.5	15.9	9.8	4 050	1 181	2 409	143	2 552	236
Prince George, B.C.	–5.8	–14.1	22.1	8.4	5 242	1 238	415	234	615	166
Port Hardy, B.C.	5.5	0.5	17.5	9.9	3 623	1 379	1 803	63	1 871	214
Kamloops, B.C.	–2.1	–8.9	28.5	13.8	3 590	2 341	184	74	258	NA
Banff, Alta.	–5.3	–14.9	22.1	7.4	5 514	1 124	281	244	468	140
Vancouver, B.C.	5.7	0.1	21.7	12.7	3 002	2 018	1 117	55	1 167	164
Victoria, B.C.	6.5	0.3	21.8	10.7	3 109	1 864	813	47	858	153
Cranbrook, B.C.	–3.9	–12.8	25.7	10.7	4 650	1 641	264	148	395	117

Note: Data based on 1961–1990 climatic normals.
NA = not available.

[a] A unit of measurement of the deviation of the mean daily air temperature from a predetermined standard (at a particular location). For further details, see definition of degree-days in Glossary.

Source: Environment Canada (1994b).

number of significant environmental problems to these regions, particularly to the southern portions of the Pacific Maritime and Montane Cordillera ecozones.

Urban sprawl — and the resulting destruction of prime agricultural land and wildlife habitat — is one of the most immediately apparent. Only a few small areas within these ecozones have the right combination of soil and climate for crop production, and most of these are in valleys or other locations that are attractive for urban development. Some of these lands are irreplaceable because they are among the very few areas in Canada suited to the production of tender fruits and grapes. As the amount of agricultural land diminishes, the quality of the remaining land may deteriorate as a result of more intensive cultivation and an increased reliance on chemical fertilizers and pesticides.

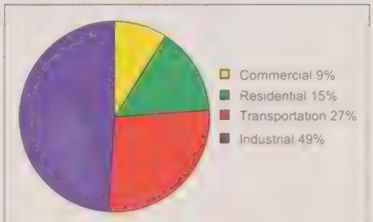
Since the early 1980s, there has been a slight decline in the total area of cropland and the number of farms in British Columbia. In the Yukon, the area of farmland has actually increased slightly as a result of a recent agricultural development program (Statistics Canada 1992). However, in areas such as the southern third of Vancouver Island, the Lower Fraser Basin, and the Okanagan Valley, the pressure on farmland is acute. In the Lower Mainland area, more than 600 ha of rural land are converted to urban uses every year (Moore 1990), even though most farmland in the Yukon and British Columbia is protected through legislation from subdivision and conversion to nonfarm uses.

In both the Lower Mainland and southeastern Vancouver Island, urban development and associated flood protection and drainage projects have eliminated wetlands, stream habitat, and other important wildlife areas. Urbanization is also having a considerable impact on some relatively rare habitats in south-central British Columbia. As population increases, these stresses will become even greater, and the need to contain urban growth through improved planning and management will become even more pressing.

Urban expansion and high levels of consumption have also created complex problems of waste management. In 1990, British Columbia sent more than 2 million tonnes of garbage to landfills or incinerators (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993). Through the Canadian Council of Ministers of the Environment, federal, provincial, and territorial governments are committed to reducing garbage disposal from 1988 amounts by 50%, on a per capita basis, by the year 2000. By the end of

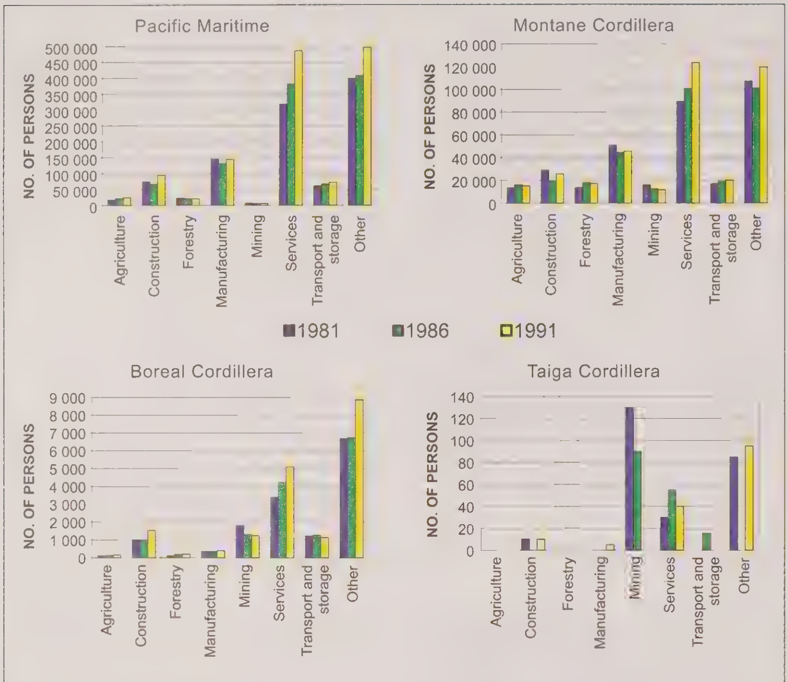
Figure 3.2

Energy use by sector, 1991



Source: Statistics Canada (1992).

Figure 3.3
Labour force trends, 1981–1991



Source: Statistics Canada (1992).

1993, a 27% reduction had been achieved in British Columbia, largely through community programs that promoted at-source reduction and reuse as well as recycling. Most Yukon communities also have recycling programs. Recyclables are shipped to Whitehorse and then on to Alberta and British Columbia for processing. In 1989, its first year of operation, the Whitehorse recycling depot accepted 56 t of aluminum and glass. By 1994, its intake had expanded to an annual total of 719 t of paper, tin, plastics, batteries, aluminum, and glass (City of Whitehorse 1995).

Generally, air quality is good within the ecozones, although some serious local problems exist, especially during periods of limited air movement, when mountains or inversions may restrict the dispersion of emissions. The worst pollution is found in the Lower Fraser Valley, where urban air pollutants, especially from motor vehicles, contribute to the formation of ground-level ozone in the summer. Smaller communities throughout British Columbia and Yukon also experience poor air quality as a result of suspended particles from the burning of sawmill wastes and wood for domestic heating. In communities where smelters or pulp mills are located, emissions of sulphur dioxide and toxic air pollutants are of concern. These problems are largely being dealt with by programs tailored to local circumstances, such as the mandatory emissions testing program for vehicles in the Greater Vancouver area and smoke control plans in other localities.

Other major environmental problems in these ecozones relate to such issues as biodiversity, forest management, toxic chemicals, and freshwater quality. Because of their special regional significance, these issues will be examined in greater detail in the following sections, as will the special problems facing the Pacific Marine ecozone and the Fraser River Basin.

Biodiversity

Biodiversity can be considered at three levels of biological organization: ecosystem, species, and genetic. Ecosystem diversity is important because genetic and species diversity tend to be greater where there is a variety of ecosystems to which species can adapt and where there has been enough time for complex ecosystems to develop. Having emerged from the last great glaciation only 10 000 years ago, most of these ecosystems are still relatively simple, characterized by mobile species that moved in quickly after deglaciation and adapted to the severe climate. The few areas that escaped glaciation, such as northwestern Yukon, the Queen Charlotte Islands, and parts of Vancouver Island, are unique, because they now contain many endemic species — ones that are peculiar to those habitats (Argus and Pryer 1990).

Ecosystem diversity

Land use and forest management practices are altering ecosystems and threatening biodiversity throughout the Boreal Cordillera, Montane Cordillera, and Pacific Maritime ecozones. Habitat loss and fragmentation pose the main risks. Roads frequently penetrate deep into natural areas; as development proceeds, the species mix changes, and ecosystem structure and function may be progressively altered (Harding and McCullum 1994). A study of 354 primary watersheds in the Pacific Maritime ecozone reported that only 20% of them were undisturbed by industrial activity; 13% were slightly modified, and over two-thirds (67%) have had some level of development (Moore 1991). In some cases, as in south-central British Columbia, some relatively rare habitats have been seriously affected (Box 3.2).

Several ecosystems in the Montane Cordillera and Pacific Maritime ecozones are more than 90% fragmented by roads and urban and rural development. The most fragmented ecosystems in the Montane Cordillera are found in the southern interior of British Columbia and include native grasslands and forests dominated by either Ponderosa Pine or Douglas-fir. The

most fragmented ecosystems in the Pacific Maritime ecozone are on the east coast of Vancouver Island and the Gulf Islands and include the dry coastal Douglas-fir forests and Garry Oak woodlands.

The Garry Oak forests, which also include two known sites on the mainland, are one of British Columbia's rarest forest types and are considered to be one of the most endangered ecosystems in North America (Schaefer 1994). Less than 5% of their original range on the Saanich Peninsula and the Gulf Islands now exists. Wildfire control and the introduction of exotic species such as Scotch Broom have also had a significant effect on these ecosystems.

Grasslands and wetlands have not fared well either. Most of the natural grasslands that existed in south-central British Columbia prior to European settlement have vanished, in part because of fire suppression, introduced species, and cattle grazing (Goward 1991; Harper et al. 1993; B.C. Ministry of Forests 1995). Much of the grassland in the Okanagan Valley, for instance, has been completely replaced by settlements, orchards, and crops. Today, many grasslands are dominated by introduced species. The few pockets of natural dry grassland that survive in the Montane Cordillera ecozone are unique in Canada, dominated by plant species such as Bluebunch Wheatgrass that rarely occur east of the Rocky Mountains.

Rangeland used for grazing by livestock may also support significant wildlife populations, such as Bighorn Sheep and Elk, particularly as winter range (B.C. Ministry of Forests 1995). As most of this land can support only a low density of grazing animals, there is a growing conflict between these uses. Grazing can also substantially alter or impair important wildlife habitat, and its effects are sometimes irreversible. Overall, there are approximately 10 million hectares of rangeland in these ecozones, including grasslands, forest clearings, riparian areas, meadows, and pastureland. Most of these lands are in British Columbia and are government owned (B.C. Ministry of Forests 1995).

Conversion to agricultural, reservoir, and urban uses is known to have caused significant wetland loss and alteration (Pilon and Kerr 1984), particularly in the southern parts of both the Pacific Maritime and Montane Cordillera ecozones. These wetlands are vital to migratory birds, but currently neither British Columbia nor the Yukon has any overall policy for their protection and enhancement.

In recent years, there has been an increase in efforts to restore damaged ecosystems. For example, British Columbia's Forest Renewal Plan makes restoring forest ecosystem health a priority, and funds are being made available for cleaning up forested watersheds (Forest Renewal B.C. 1995). There have also been significant efforts to restore marine wetland habitats in the Strait of Georgia. As well, land use planning processes initiated by the Commission on Resources and Environment have developed land use plans that include lands for protection. More stringent pulp and paper mill regulations have helped to considerably reduce discharges of some contaminants, including chlorine-based compounds (B.C. Ministry of Environment, Lands and Parks 1995a). In addition, B.C. government regulations call for the restoration of sites disturbed by mining; however, of the 31 000 ha that have been disturbed, only 27% have actually been restored so far. In the Yukon, regulations governing mining and mineral exploration are limited to the protection of public safety and water resources, and there are no requirements for restoration of disturbed lands.

Species diversity

Terrestrial and aquatic organisms

Although comprising only about 10% of Canada's land area, British Columbia has over 50% of the country's estimated 4 150 vascular plants, 70% of its 454 bird species, and 80% of its terrestrial mammals (B.C. Ministry of Forests 1995). Biologists estimate that 1 000 species of moss and liverwort, 1 000 lichen species, 10 000 species of fungi, and 35 000 insect species

Box 3.2
The Okanagan: fragile ecosystems face increasing pressures

Small and extremely fragile, the semiarid ecosystems of the Okanagan Basin provide habitat for some of the most diverse, unique, and rare groupings of plant and animal species in Canada (Harper et al. 1993). The basin has more species of mammals, birds, reptiles, and amphibians at risk than any other area within this ecozone (Page et al. 1991). Many South Okanagan species exist nowhere else in Canada. However, less than 3% of the basin has protected status.

A number of pressures threaten biological diversity in the region. Urbanization and agricultural development are responsible for most of the natural habitat losses. Introduced species (e.g., domesticated plants and animals, Eurasian Water Milfoil, Purple Loosestrife, Diffuse Knapweed, Fox Squirrel, and European Starling) are widespread and are overwhelming many native species (Harper et al. 1993). Unnatural increases in native species have also occurred. Livestock grazing is disturbing the soil and reducing the water supply in temporary pools used by wildlife. Grazing also reduces fuel for natural wildfires and, along with fire suppression, is altering habitat by changing the composition of plant species in the grasslands. In addition, timber harvesting is reducing winter range for some species as well as destroying nesting or roosting habitats, such as tree snags for cavity-nesting birds and bats.

Approximately 3 000 deer are hit and killed on Okanagan highways each year. So are many more smaller animals, including scarce amphibians and reptiles. By providing plenty of carcasses for scavenging, large numbers of road-killed animals also sustain predator populations at higher-than-usual levels. Further damage is caused by all-terrain vehicles, which disturb wildlife and degrade habitats by exposing sensitive soils and allowing the invasion of noxious weeds.

are also present. Of native Canadian species, 9% of the breeding birds, 12% of the reptiles, 17% of the mammals (excluding those in the sea), and 27% of the amphibians are exclusive to British Columbia. In addition, the province has 50–75% of the world's Stone Sheep, Mountain Goats, Blue Grouse, and Trumpeter Swans (McKelvey 1981; B.C. Ministry of Forests 1995).

However, biologists have estimated the present status of only a few hundred of these species. Past trends are known for even fewer. Those that are best documented include several species of marine mammals and seabirds that congregate annually to breed and commercially managed fish and invertebrate species. Because of its links to the socioeconomic and environmental fabric of the North, much is also known about the Grant's Caribou, particularly the Porcupine herd (Box 3.3).

As of April 1995, the national Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed 65 species at risk in the five ecozones (Table 3.1). While inclusion on the list highlights the plight of these species, it does not necessarily imply or lead to any government action to protect them. About half of all of the species are found in the Montane Cordillera ecozone.

Approximately 65% of the listed species fall into the "vulnerable" category, but, for the majority of species, population trends are either poorly understood or not known. Biologists estimate that most of these populations are stable at best or still decreasing. Overall, there are at least 24 wildlife species that are extinct or have been extirpated from these ecozones. Several, however, have been reintroduced, including the Burrowing Owl, Wood Bison, and Sea Otter (Harding and McCullum 1994).

There has been little recent population change among the 80 or so species of freshwater fishes that inhabit these ecozones, but about 36 species or subspecies are being tracked by the British Columbia Conservation Data Centre because of concerns about their vulnerability. Over 25% of the tracked species are found nowhere else in Canada, and there are serious concerns about the survival of some, such as the Salish Sucker, White Sturgeon, and Enos Lake Stickleback. Populations of Cutthroat Trout, Dolly Varden, Steelhead, and other larger and better known species face a number of stresses, especially in southern parts of the Pacific Maritime and Montane Cordillera ecozones. These include sportfishing, habitat disruption, reduced natural survival, incidental catches in other fisheries, poor logging practices along streams, and poaching. Sampling of 25 streams on Vancouver Island has revealed that only 30–55% of the potential

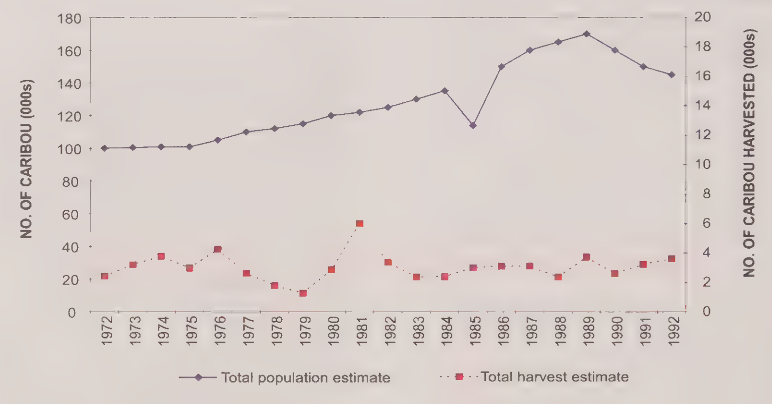
Box 3.3
Porcupine Caribou herd

The Porcupine Caribou herd, a large population of migrating Grant's Caribou, has been an important part of northern Yukon's natural environment for thousands of years. During the 1980s, the herd grew approximately 5% per year, numbering 178 000 by 1989. By 1994, however, the herd had declined to 152 000 (Fig. 3.B1). Biologists are uncertain of the reason for the decline but speculate that severe winter and spring conditions in the early 1990s may have been a major contributing factor.

The range of the herd includes much of northeastern Alaska, northern Yukon, and the Richardson Mountains of the Northwest Territories. The herd is an important source of food for Gwitchin, Inuvialuit, and Inupiat from 13 communities in these areas and is also hunted by non-Native residents. Over the past 15 years, the reported harvest has ranged from 2 000 to 7 000 head per year. The herd also supports predators such as wolves, Grizzly Bears, and Golden Eagles. These Caribou are most sensitive to disturbance while on their calving grounds and less so while on their winter range.

Since 1980, the Canadian government, the governments of the Yukon and Northwest Territories, several Native groups, and the U.S. government have concluded agreements or passed legislation that has greatly increased the protection of the herd's habitat. The main threat to the herd is the potential for serious disturbance of important calving grounds on Alaska's North Slope if proposals to allow oil exploration in the Alaska National Wildlife Refuge are approved.

Figure 3.B1
Estimated total population and total annual harvest of the Porcupine Caribou herd, 1972–1992



Source: Yukon Department of Renewable Resources and Environment Canada (1995).

Table 3.1
Status and trends of COSEWIC-listed animal and plant species within the five western ecozones

Species	Trends	COSEWIC status	Estimated population/location	Ecozone occurrence
Mammals				
Grizzly Bear	Declining	Vulnerable	Approx. 14 000	All terrestrial ecozones
Wood Bison	Increasing	Threatened	400	Boreal Cordillera
Woodland Caribou	Stable	Vulnerable	11 000 B.C. 15 000 Yukon	Boreal Cordillera
Fringed Myotis Bat	Unknown	Vulnerable	Only in South Okanagan	Montane Cordillera Pacific Maritime
Keen's Long-eared Bat	Unknown	Vulnerable	Unknown	Pacific Maritime
Pallid Bat	Declining	Vulnerable	Only in South Okanagan	Montane Cordillera
Spotted Bat	Declining	Vulnerable	Only in South Okanagan	Montane Cordillera
Pacific Water Shrew	Declining	Threatened	Only in lower Fraser Valley	Pacific Maritime
Sea Otter	Increasing	Endangered	Unknown	Pacific Marine
Blue Whale	Stable	Vulnerable	Unknown	Pacific Marine
Fin Whale	Increasing	Vulnerable	16 000–20 000 (North Pacific)	Pacific Marine
Humpback Whale	Stable	Threatened	2 000	Pacific Marine
Right Whale	Declining	Endangered	Unknown	Pacific Marine
Queen Charlotte Islands Ermine	Unknown	Vulnerable	Unknown	Pacific Maritime
Western Harvest Mouse	Unknown	Vulnerable	Okanagan and Similkameen valleys	Montane Cordillera
Nuttall's Cotton-tail Rabbit	Stable	Vulnerable	Okanagan and Similkameen valleys	Montane Cordillera
Vancouver Island Marmot	Declining	Endangered	200–400	Pacific Maritime
Wolverine	Stable–increasing	Vulnerable	10 000–15 000	All terrestrial ecozones
Birds				
Yellow-breasted Chat	Stable–declining	Threatened	<50 breeding pairs; only in Okanagan Valley	Montane Cordillera
Ancient Murrelet	Declining	Vulnerable	540 000	Pacific Maritime Pacific Marine
Marbled Murrelet	Declining	Threatened	36 000	Pacific Maritime Pacific Marine
Long-billed Curlew	Declining	Vulnerable	300–500	Montane Cordillera
Cooper's Hawk	Stable	Vulnerable	Unknown	Montane Cordillera
Anatum Peregrine Falcon	Declining	Endangered	Approx. 12 pairs in B.C.	All terrestrial ecozones
Peale's Peregrine Falcon	Stable	Vulnerable	60 pairs (Queen Charlotte Islands)	Pacific Maritime
Tundra Peregrine Falcon	Stable–declining	Threatened	560 pairs in Canada	Taiga Cordillera
Mountain Plover	Unknown	Endangered	Unknown	Montane Cordillera
Piping Plover	Unknown	Endangered	Unknown	Pacific Maritime
Sage Thrasher	Stable	Endangered	Approx. 12 pairs (only South Okanagan)	Montane Cordillera
Ivory Gull	Declining	Vulnerable	Minimal occurrence outside Arctic	All ecozones
Northern Goshawk	Declining	Vulnerable	Unknown	Pacific Maritime
Burrowing Owl	Declining	Endangered	<40 birds	Montane Cordillera
Barn Owl	Declining	Vulnerable	250–275 breeding pairs	Pacific Maritime
Great Grey Owl	Stable	Vulnerable	5 000–50 000 (North America)	All terrestrial ecozones
Flammulated Owl	Stable	Vulnerable	Unknown	Montane Cordillera
Short-eared Owl	Unknown	Vulnerable	Unknown	All terrestrial ecozones
Spotted Owl	Declining	Endangered	<100 pairs in B.C.	Pacific Maritime
Trumpeter Swan	Stable	Vulnerable	5 400 in North America	All ecozones
Caspian Tern	Unknown	Vulnerable	5 100 in Canada	All ecozones
White-headed Woodpecker	Unknown	Threatened	Only in Okanagan and Similkameen valley area	Montane Cordillera
Amphibians and reptiles				
Pacific Giant Salamander	Unknown	Vulnerable	Unknown	Pacific Maritime
Leatherback Turtle	Declining	Endangered	Migrant	Pacific Marine

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Table 3.1 (continued)
Status and trends of COSEWIC-listed animal and plant species within the five western ecozones

Species	Trends	COSEWIC status	Estimated population/location	Ecozone occurrence
Fish				
Speckled Dace	Unknown	Vulnerable	Only along Granby and Kettle rivers	Montane Cordillera
Umatilla Dace	Unknown	Vulnerable	Unknown	Montane Cordillera
Pacific Sardine	Unknown	Vulnerable	Only offshore Vancouver I. and south	Pacific Marine
Green Sturgeon	Stable	Vulnerable	Unknown	Pacific Maritime
White Sturgeon	Declining	Vulnerable	Unknown	Pacific Maritime Boreal Cordillera Montane Cordillera
Lake Lamprey	Stable	Vulnerable	Only in Cowichan and Mesachie lakes	Pacific Maritime
Charlotte Unarmoured Stickleback	Stable	Vulnerable	Approx. 400 000	Pacific Maritime
Giant Black Stickleback	Stable	Vulnerable	>200 000 (only in Mayer Lake, Graham I.)	Pacific Maritime
Enos Lake Stickleback	Stable	Threatened	Only in Enos Lake	Pacific Maritime
Shorthead Sculpin	Stable	Threatened	>40 000	Montane Cordillera
Salish Sucker	Declining	Endangered	Lower Fraser Valley	Pacific Maritime
Squanga Whitefish	Stable	Vulnerable	Only in 4 Yukon lakes	Boreal Cordillera
Plants				
Giant Helleborine	Unknown	Threatened	Unknown	Montane Cordillera
Cryptic Paw Lichen	Declining	Vulnerable	21 coastal and interior sites	Pacific Maritime Montane Cordillera
Bolander's Quillwort	Stable	Vulnerable	2 sites (Waterton Lakes National Park)	Montane Cordillera
Golden Paint Brush	Declining	Threatened	<4 000 plants	Pacific Maritime
Yellow Montane Violet	Declining	Threatened	8 sites	Pacific Maritime
Mosquito Fern	Declining	Threatened	Unknown	Montane Cordillera
Small-flowered Lipocarpa	Declining	Threatened	Unknown	Montane Cordillera
Southern Maidenhair Fern	Declining	Endangered	1 location only (Columbia Lake)	Montane Cordillera
Macoun's Meadowfoam	Unknown	Vulnerable	Southwest B.C.	Pacific Maritime
Western Blue Flag	Unknown	Threatened	Very localized	Montane Cordillera
Phantom Orchid	Unknown	Vulnerable	12 sites (southwest B.C.)	Pacific Maritime

Source: Committee on the Status of Endangered Wildlife in Canada (1995).

spawning population of Steelhead has returned since the mid-1980s (G. Reid, B.C. Ministry of Environment, Lands and Parks, personal communication).

Salmon stocks are of concern in both the Yukon and British Columbia as a result of natural factors as well as overfishing, industrialization, urbanization, and the dilution of genetically diverse natural stocks by hatchery populations. In the Yukon, further difficulties arise because the lower reaches of the major salmon rivers, the Alsek and the Yukon, flow through Alaska. As Alaskans get to harvest these fish first as they move upstream, the ultimate health of the stocks depends on that state's management efforts. In addition, the salmon may also be captured in the ocean by foreign fishing fleets. Yukon and Alsek river Chinook populations are stable but low in abundance, while Chum populations have declined and remain low. Alsek River Sockeye are stable at moderate levels (Yukon Department of Renewable Resources and Environment Canada 1995).

Marine organisms

The status and trends of 70 species or groups of marine plants and animals are summarized in Table 3.2. These were selected because of the availability of long-term information from commercial harvest records and surveys of breeding sites. Roughly 70% of these species or populations, including many marine mammals and seabirds, are currently at average historical numbers or higher. The rest, especially the invertebrates and fishes (including some salmon), are at historical lows.

Natural factors, acting either alone or in conjunction with harvesting and other human stresses, explain some of these fluctuations. In some cases, however, population trends are unknown or based on limited information. There is more uncertainty, for example, about population estimates of species such as nocturnal, burrow-nesting seabirds that are expensive or difficult to census.

Some previously declining species, such as the Pacific Herring, have made strong comebacks. Herring are probably the most abundant prey food in Canada's Pacific

Table 3.2
Status and abundance trends of selected biota within the Pacific Marine ecozone

Group/species	Present status[a]	Recent trend	Comments
INVERTEBRATES[b]			
Abalone	Low	Decreasing–stable	Harvest banned coastwide
Geoduck	Average	Decreasing	Biomass not known
Clams (5 species)	Low–average	Decreasing	Fishery under revision
Octopus	Average	Stable	Capture by chemicals now banned
Oysters (3 species)	Unknown	Decreasing	
Shrimp (6 species)	Average–high	Stable	
Dungeness Crab	Low–average	Decreasing	Catch/effort data inadequate
GROUNDFISH[b]			
Dogfish	Average–high	Stable	Harvest limited
Pacific Halibut	Average	Decreasing–stable	Improvement expected
Pacific Hake	Average	Decreasing	Fluctuations largely natural
Lingcod	Low–average	Stable	
Pacific Cod	Low	Decreasing	Status highly stock-dependent
Pollock	Average	Unknown	Harvest has increased recently
Pacific Ocean Perch	Low–average	Stable	
Rockfish (9 species)	Low–average	Decreasing–stable	Status highly stock-dependent
Sablefish	Average	Decreasing–stable	
Skate (2 species)	Average	Unknown	Harvesting is sporadic and minor
Sole (4 species)	Average–high	Increasing	Petrale Sole has low recruitment
Turbot	Average	Stable	Harvest is by-catch of other fisheries
SALMONIDS[b]			
Chinook Salmon	Low–high	Decreasing–increasing	Strait of Georgia stocks not rebounding
Sockeye Salmon	Low–high	Increasing	
Coho Salmon	Low–average	Decreasing	Some wild populations have been lost
Pink Salmon	Average–high	Stable–increasing	
Chum Salmon	Average–high	Stable	
Steelhead	Low–average	Decreasing	Many populations at risk
OTHER FISHES			
Pacific Herring	Low–high	Stable–decreasing	Fluctuations largely natural
Eulachon	Low	Unknown	
Surf Smelt	Average	Stable	Harvest has increased recently
White Sturgeon	Low	Decreasing	Life history uncertain
MAMMALS			
Killer Whale	Average	Increasing	
Grey Whale	High	Increasing	
Steller Sea Lion	Average	Increasing	
California Sea Lion	High	Stable	
Harbour Seal	High	Increasing	
SEABIRDS[c]			
Fork-tailed Storm-Petrel	High	Unknown	Significant impact from introduced predators on Queen Charlotte Islands
Leach's Storm-Petrel	High	Unknown	Significant impact from introduced predators on Queen Charlotte Islands
Cassin's Auklet	High	Stable	Significant impact from introduced predators on Queen Charlotte Islands

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Table 3.2 (continued)
Status and abundance trends of selected biota within the Pacific Marine ecozone

Group/species	Present status[a]	Recent trend	Comments
Rhinoceros Auklet	High	Stable	Significant impact from introduced predators on Queen Charlotte Islands
Pelagic Cormorant	Average	Stable	Widespread coastal breeder
Double-crested Cormorant	High	Increasing	Restricted to Strait of Georgia
Brandt's Cormorant	High	Unknown	Irregular breeder, common in winter
Glaucous-winged Gull	High	Increasing	Species is invading sites
Common Murre	High	Decreasing	Scarce breeder, occurs mostly on Triangle Island
Thick-billed Murre	Low	Unknown	At limit of range, found only on Triangle Island
Pigeon Guillemot	High	Increasing	Scattered, difficult to census
Tufted Puffin	Low	Stable	Occurs mostly on Triangle Island
Horned Puffin	Low	Unknown	At limit of range

[a] Status classes:
high = species or population at or near its highest historical level of abundance
average = species or population at midrange between highest and lowest historical levels of abundance
low = species or population at or near lowest historical level of abundance

[b] For invertebrates, groundfish, and salmonids, judgements of PRESENT STATUS are best estimates of today's abundance relative to historical levels of the past decade or more. Judgements of RECENT TRENDS are best estimates of abundance changes over the past five or so years.

[c] For seabirds, PRESENT STATUS derived from the regular occurrence status categories of abundant (=high), common (=average), and uncommon and rare (=low), as reported by Campbell et al. (1990). Similarly, RECENT TRENDS correspond to increases or decreases in distribution or numbers of birds whose status has changed significantly since 1947 as per Campbell et al. (1990).

Source: Bigg (1988a, 1988b); Campbell et al. (1990); Olesiuk et al. (1990a, 1990b); Klinowska (1991); Lane (1991); PSARC Steering Committee (1992, 1994, 1995); International Pacific Halibut Commission (1995); G.W. Kaiser, personal communication; J.C. Watson, G.M. Ellis, T.G. Smith, and J.K.B. Ford, unpublished data.

coastal waters and are crucial to both the marine food web and the commercial fishery. They make up 30–70% of the summer diets of Chinook Salmon, Pacific Cod, Lingcod, and Harbour Seals in southern B.C. waters. The commercial harvest employs up to 6 000 people and provides $180 million in revenues (Environment Canada 1994a). For these reasons, and because their habitat is threatened by coastal development, spills, and other pollution, the Pacific Herring has been chosen as a regional indicator of the state of the marine environment.

Until the late 1960s, British Columbians harvested up to a quarter of a million tonnes of these fish a year, to be processed into fish meal and oil. Decades of overfishing, however, greatly depleted the breeding stock, and by 1965 only 15 000 t of spawning herring were left. In 1967, the federal government stopped virtually all commercial fishing for the species along the entire coast for four years.

Within five to six years, however, most of the stocks recovered dramatically to a spawning biomass of 100 000–200 000 t (Fig. 3.4). A new fishery for herring roe was begun, initially on an experimental basis, and has now been operating under strict control for the past 20 years. Today, no more than 20% of the anticipated annual stock of herring swollen with ripe eggs can be netted, and stocks that are in poor condition because of natural fluctuations are closed to all fishing for a year or more.

In 1993, federal fisheries biologists reported that four of the five B.C. stocks of Pacific Herring were in average to good condition. The other was in poor condition because of fluctuations in ocean conditions.

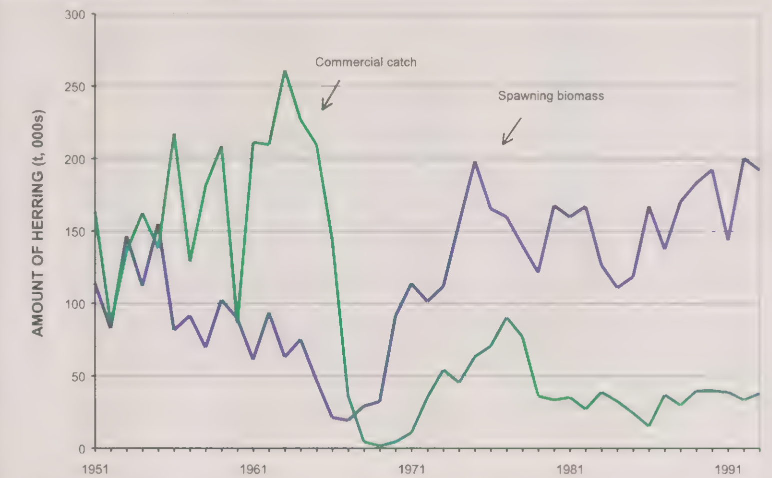
Killer Whales are also gradually increasing in numbers. Of the three distinct coastal populations of Killer Whales in B.C. waters, the northern residents — which inhabit the area north of a line through the middle of Vancouver Island — now number over 200 animals and are increasing at a rate of 2.9% per year. There are over 90 southern residents, and they are increasing by about 1.3% a year. Much less is known, however, about the estimated 170 transients that range along the entire coast or the approximately 200 offshore Killer Whales that occasionally approach the Queen Charlotte Islands (Fig. 3.5).

Genetic diversity: Pacific salmon

Since the retreat of the glaciers, the precise homing of Pacific Salmon to natal streams and other adaptive processes have resulted in the formation of locally adapted, genetically distinct, and largely isolated spawning groups. However, only recently has concern increased about the loss of this biological diversity as a result of overharvesting and other environmental pressures.

In southwestern British Columbia, one-third of about 500 salmon populations monitored since the early 1950s have steadily declined and have been lost or have decreased to such low levels that biologists no longer consistently count them (Fig. 3.6). The smaller populations — those with only 100–999 spawning fish — have suffered the greatest losses. Although their destruction may have had only limited

Figure 3.4
Spawning biomass and commercial catch of Pacific Herring, 1951–1993



Source: Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C.

Figure 3.5
Abundance of Killer Whales in British Columbia, 1974–1993

Note: No trend data prior to 1993 for transient and offshore populations.
Source: Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, B.C.

impacts on the commercial catch to date, the loss of their genetic diversity may prove to be serious in the future.

To sustain Pacific salmon, the stewardship of remaining populations must be improved. Hatchery stocks cannot make up for lost natural populations because they are derived from a few individuals and represent only a small portion of the genetic diversity within a species. Nor is it enough to concentrate only on the preservation of larger populations. Smaller populations represent a significant genetic resource that must be protected too. An even greater challenge is to protect the habitat where salmon spawn and feed in the midst of growing human population and expanding economies. Salmon conservation also requires more educational programs, research, and better decisions that recognize the biological as well as the economic value of these species and habitats.

Protected areas

Protected areas have a key role to play in preserving biodiversity. Currently, there are well over 800 such areas within the four terrestrial ecozones, encompassing more than 14 million hectares (Fig. 3.7).

Using the six-level classification scheme developed by the World Conservation Union (IUCN), 85% of these areas are in categories I–III, which require strict protection of natural areas, species, and ecosystems. The remaining 15% are found in categories IV–VI, which allow human intervention when it is compatible with conservation objectives (Fig. 3.8).

Size is critical in determining the sustained viability of protected areas. Large protected areas generally have more ecological value and are better able to maintain biodiversity than small ones. However, small protected areas play an important role in preserving natural heritage by affording protection to some rare and endangered species and their habitats, as well as linking reserves. Of the highly protected areas (classes I–III), a vast majority are less than 1 000 ha (IUCN considers protected areas >1 000 ha as significant for ecosystem protection). Figure 3.8 illustrates the spectrum of size-classes of the protected areas occurring within these ecozones in 1994, for all IUCN categories. As of summer 1995, 133 protected areas within British Columbia were less than 10 ha in size, 190 were larger than 1 000 ha, 89 were larger than 10 000 ha, and 25 were larger than 100 000 ha (B.C. Ministry of Environment, Lands and Parks 1995b).

The larger protected areas include Ts'yl-os (Chilco Lake) in the Montane Cordillera, a 2 332-km² provincial park that is home to species such as the Californian Bighorn Sheep and to British Columbia's third largest Sockeye Salmon run; and the Kitlope Valley in the Pacific Maritime ecozone, which contains 3 170 km² of the largest intact coastal temperate rain forest

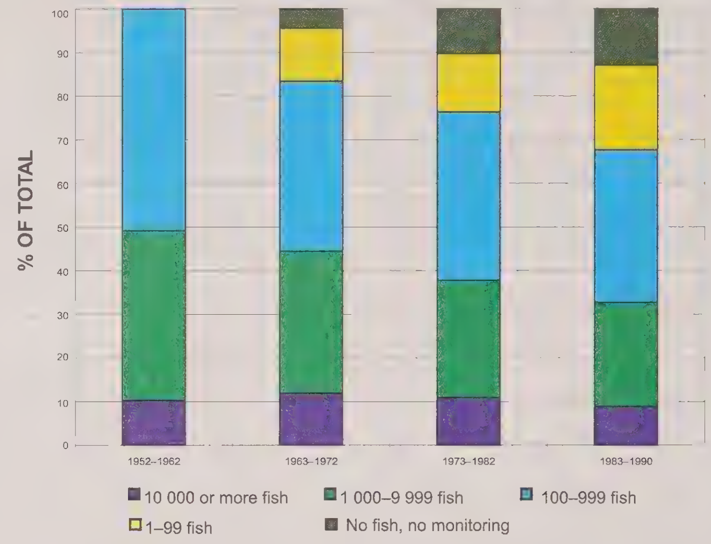
in the world. Among other significant protected lands, the Tatshenshini–Alsek Wilderness Area in the Boreal Cordillera provides an essential link in the creation of the world's largest contiguous protected area, while the Khutzeymateen Valley in the Pacific Maritime ecozone is Canada's first Grizzly Bear sanctuary (Box 3.4).

The British Columbia Protected Areas Strategy, established in July 1992, commits the province to protect 12% of its area by the year 2000. The principal goal of the strategy is to protect viable, representative examples of the natural diversity of the province, including special natural, cultural heritage, and recreational features. The amount of protected land in British Columbia has increased from 6.3% of the province's area in 1990 to 9.1% in 1995 (B.C. Ministry of Environment, Lands and Parks 1995b).

In addition, recent amendments to British Columbia's *Land Title Act* allow designated nongovernmental organizations to register conservation covenants on title to private land to protect it for ecological purposes. These voluntary commitments to private land stewardship are an important complement to British Columbia's Protected Areas Strategy for Crown land and are becoming a critical component in ensuring the future viability of a substantial percentage of British Columbia's sensitive habitats and species. Currently, such programs are under way in four areas: Delta, Courtney/Comox, Cowichan/Chemainus, and the South Okanagan. In cooperation with the federal government and organizations such as Wildlife Habitat Canada, the provincial government has announced the creation of a three-year Stewardship Pledge Program to promote and coordinate private stewardship activities throughout the province.

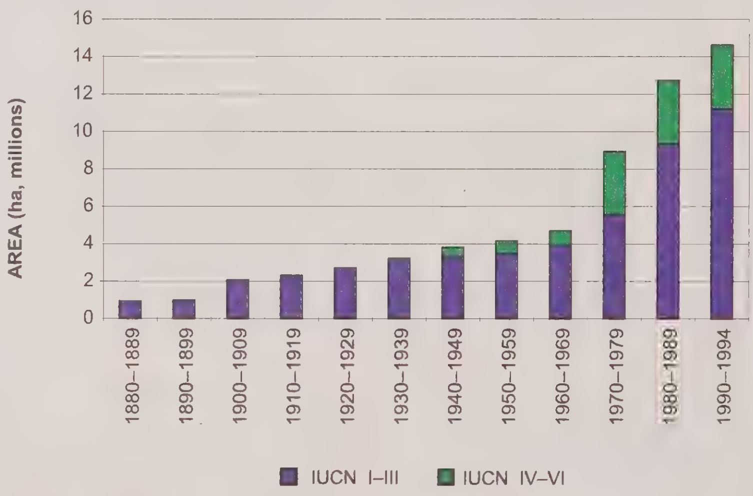
In the Yukon, 44 735 km² of land, or about 9% of the territory, are protected. Over 80% of these lands fall within the highly protected IUCN categories I–III. Examples include Kluane National Park, Vuntut National Park, and Coal River Springs Territorial Park (Yukon Department of Renewable Resources and Environment Canada 1995).

Figure 3.6
Spawning numbers of salmon populations in southwestern British Columbia, 1952–1990



Source: Based on monitoring of 495 representative populations by the Department of Fisheries and Oceans (Riddell 1993).

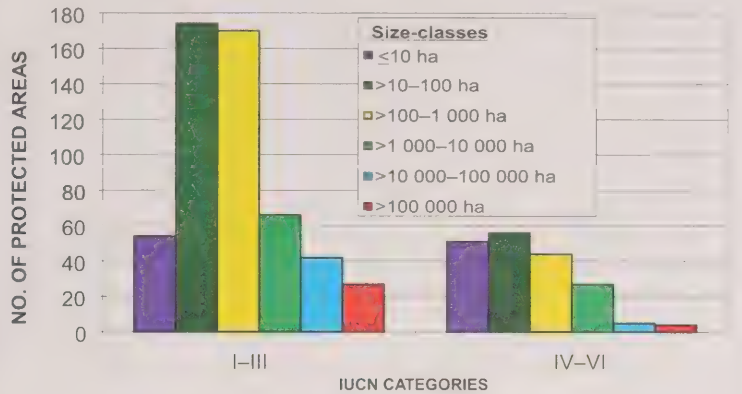
Figure 3.7
Trends in growth of terrestrial protected areas in the region, by IUCN categories, 1880–1994



Note: No IUCN category III protected areas have been classified for the four western terrestrial ecozones.

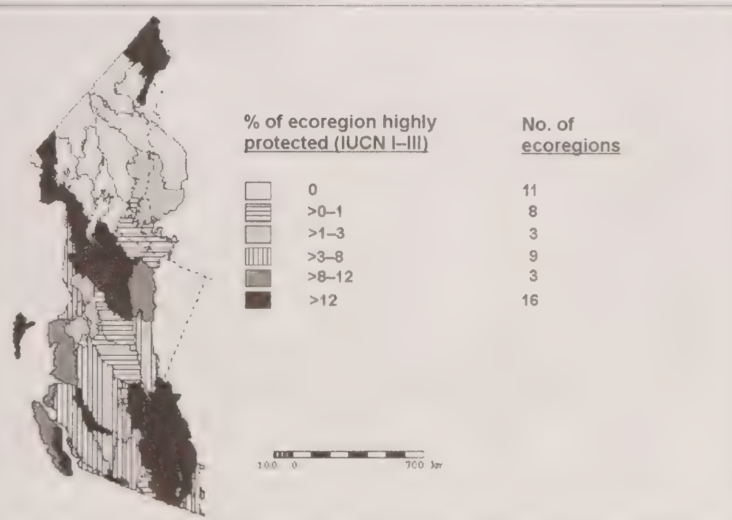
Source: National Conservation Areas Database, State of the Environment Directorate, Environment Canada.

Figure 3.8
Number of terrestrial protected areas in the region, by IUCN categories and size-class, 1994



Source: National Conservation Areas Database, State of the Environment Directorate, Environment Canada.

Figure 3.9
Percentage of ecoregions in IUCN classes I–III (highly protected), 1994



Source: National Conservation Areas Database, State of the Environment Directorate, Environment Canada

Several natural features within these ecozones have been recognized by international conservation programs. Among these are three world heritage sites: Ninstints on Anthony Island (Pacific Maritime), part of the Rocky Mountains (Montane Cordillera), and the Tatshenshini–Alsek Wilderness Area (Boreal Cordillera). Three areas, Alaksen (Pacific Maritime), Creston Valley Wildlife Management Area (Montane Cordillera), and Old Crow Flats (Taiga Cordillera), have been designated as Wetlands of International Importance under the Ramsar Convention (The Convention on Wetlands of International Importance Especially as Waterfowl Habitat, Ramsar, Iran, 1971).

While progress has been made on increasing the extent of protected areas, there are still concerns about whether these areas are truly representative of the region's ecology or weighted towards unique ecosystems. One objective of British Columbia's Protected Areas Strategy is to increase protection of ecosystem diversity. The amount protected will vary with each ecosection of the province, to meet the overall goal of 12%. As of 1994, 17 of 24 ecosections in the Pacific Maritime ecozone, 34 of 53 in the Montane Cordillera, and 4 of 15 in the Boreal Cordillera still had less than 1% representation in protected areas. Six of the 23 ecoregions that comprise the Yukon have protected areas within them. Figure 3.9 shows the distribution of highly protected areas in the ecoregions of the four terrestrial ecozones.

Progress in the establishment of marine protected areas over the last two decades has also been modest. Of the more than 27 000 km of coastline, 6 500 coastal islets, and 290 000 km^2 of ocean (area of the Pacific Ocean within Canada's 200-nautical-mile territorial limit), only 4 946 km^2 or 1.7% of British Columbia's marine waters are under some form of protected status. The most significant marine ecological reserves include Robson Bight (1 248 ha), Checleset Bay (33 150 ha), and Byers, Conroy, Harvey, and Sinett islands (11 780 ha). Other marine areas have been established as extensions to terrestrial parks or ecological reserves to protect significant marine features such as marine mammal haulouts, seabird nesting colonies, estuaries, and unique coastal landforms (B.C. Land Use Coordination Office 1994). B.C. Parks, for example, manages 53 provincial parks and 11 ecological reserves whose marine components cover a total area of 1 400 km^2

Parks Canada currently protects 155 km^2 of marine waters off the west coast of Vancouver Island in Pacific Rim National Park Reserve. It is also in the process of

establishing a national marine conservation area of over 3 400 km^2 surrounding Gwaii Haanas National Park Reserve on the south end of the Queen Charlotte Islands. In addition, the Canadian Wildlife Service has established five migratory bird sanctuaries along British Columbia's coast, totalling 2 512 ha.

Other initiatives, involving partnerships between governmental and nongovernmental organizations, focus on protection of coastal wetlands. Through the Pacific Coast Joint Venture and the Pacific Estuary Conservation Program, 12 074 ha of wetlands have been protected, including the Fraser River South Arm Marshes Wildlife Management Area, Kumdis Bay (Queen Charlotte Islands), Englishman River estuary (on Vancouver Island), and Gunn Island in the Fraser River delta and lands adjacent to Boundary Bay.

A marine protected areas strategy for the Pacific Marine ecozone is being prepared jointly by the federal and B.C. governments. It will include common objectives and principles for the establishment and management of these areas. The intent is to ensure protected status for areas representative of the full range of marine ecosystems along the coast of British Columbia.

Another major concern about protected areas is that many of them are becoming islands in a sea of development, with their ecological integrity threatened by habitat destruction and fragmentation. These problems are becoming increasingly apparent in the five Rocky Mountain national parks — Banff, Jasper, Kootenay, Yoho, and Waterton Lakes.

Within these parks, transportation corridors remove habitat, form barriers to the movement of wildlife, and are a direct cause of wildlife mortality. Townsites and other developments further fragment the landscape (Fig. 3.10). In Banff, for example, development already severely restricts access to important wildlife habitats. The boundaries of the town are now legislated, but increases in the density of development continue. Ironically, values that many visitors seek are steadily being eroded to accommodate them.

Box 3.4
Khutzeymateen/K'tzim-a-diin Grizzly Bear Sanctuary

The Khutzeymateen/K'tzim-a-diin Grizzly Bear Sanctuary (Fig. 3.B2) is the first area in Canada to be protected specifically for Grizzly Bears and their habitat. Located in the Western Kitimat Ranges of the Pacific Maritime ecozone, approximately 45 km northeast of Prince Rupert, the sanctuary encompasses 44 300 ha.

The Khutzeymateen/K'tzim-a-diin area was declared a Class "A" Provincial Park in 1994 in an announcement by the provincial government and the Gitsi'is people. Both the land and the Grizzly Bear have spiritual significance to the Gitsi'is, within whose traditional territory the park is located.

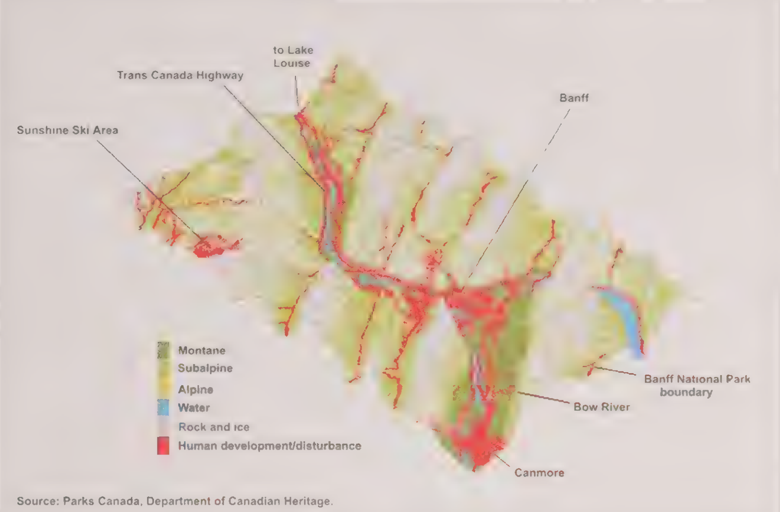
An abundance of wildlife shares the sanctuary, including Black Bears, Mountain Goats, martens, Wolverines, wolves, porcupines, otters, beavers, and Harbour Seals. The watershed also supports songbirds, raptors, waterfowl, and numerous other woodland and shorebirds, including the elusive Marbled Murrelet. Runs of Chinook, Coho, and Chum salmon, as well as Steelhead, occur in both the Khutzeymateen and Kateen rivers.

Figure 3.B2
Khutzeymateen/K'tzim-a-diin Grizzly Bear Sanctuary

Outside the parks, adjacent provincial lands that once formed extended blocks of wilderness are now subjected to a variety of developments, including new roads and resource extraction activities. In Yoho and Kootenay parks, for example, clear-cuts extend right up to the park boundaries. The net effect ecologically is to decrease the effective size of the habitats provided by the parks.

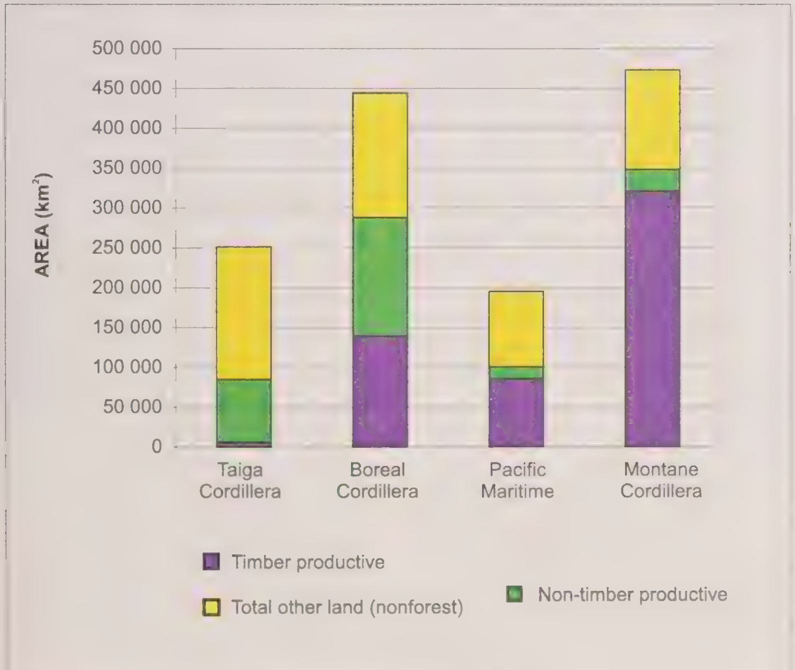
As wildlands shrink and become increasingly isolated from each other, they are less able to support certain species. Large carnivores, such as Grizzly Bear, Black Bear, wolf, Cougar, and Wolverine, are often the first to be threatened. Some species simply begin to disappear for reasons that are not entirely understood, as is the case with Moose in the Banff Bow Valley. Other species become problem

Figure 3.10
Human activity in the Lower Bow Valley



Source: Parks Canada, Department of Canadian Heritage.

Figure 3.11
Forested land by ecozone, 1991



Source: Canada's Forest Inventory, Petawawa National Forestry Institute.

wildlife in towns and campsites and have to be removed (e.g., Elk in Banff and Cougar in Waterton). In addition, large numbers of bear, Elk, wolf, and other wide-ranging species are killed on those parts of their range that lie outside the parks, especially in jurisdictions where they are considered a nuisance.

As a result of concerns about the cumulative effect of these impacts in the Bow Valley, the Minister of Canadian Heritage initiated an intensive study of the area in 1994. When completed, the study will provide a baseline for understanding the effect of present and future development and human use on these heritage resources and should lead to improved management and land use strategies.

The Changing Forests

The four western terrestrial ecozones contain over 82 million hectares of forest, approximately 55 million of which are considered timber productive — that is, lands capable of producing commercial forest tree species. Because this designation also includes protected and other noncommercial forests, only about one-half of the timber-productive forest is actually available for commercial harvest. Both the largest proportion of forested land (74% of the ecozone) and the largest area of timber-productive forest (68%) are found in the Montane Cordillera (Fig. 3.11).

Economically, the timber sector is of great importance, particularly in the Pacific Maritime, Boreal Cordillera, and Montane Cordillera ecozones. In 1993, \$9.7 billion worth of solid wood products and \$4 billion of pulp and paper products were exported from these ecozones. Forestry is also vital to many small towns in this part of Canada: in 1993, the regional forest industry supported approximately 90 000 direct and 135 000 indirect jobs, or 6% and 9%, respectively, of British Columbia's total employment (Statistics Canada 1992).

Recreation is also now a major forest use in the region. In British Columbia, about

$2.4 billion was spent on recreational uses in provincial forests in 1993 — about 67% on road-accessed activities and 33% on roadless backcountry recreation (B.C. Ministry of Forests 1995). Current annual recreational use for B.C. forests, inside and outside parks, is over 80 million user-days and growing, with nature study, including scenic viewing, the most common activity. Forests also have spiritual and recreational values that are not easily quantified. These factors are increasingly influencing the nature of timber management.

Forest composition

The forests in each ecozone differ considerably in species composition, age structure, ecological characteristics, economic importance, and other characteristics. In the Montane Cordillera ecozone, where the most diverse mix of ecosystems in Canada is found, forest types run the gamut from Subalpine Fir and interior rain forests to the dry interior Douglas-fir and Ponderosa Pine forests. The Pacific Maritime ecozone has remnants of the rare Garry Oak–arbutus ecosystems and the largest tracts of temperate rain forests on the Pacific West Coast (Box 3.5). The two northern ecozones are transitional areas, with full boreal forests of spruce and pine in the south and sparse tree cover in sheltered areas at northern latitudes and upper elevations.

A general breakdown of tree types and age-classes for each ecozone is presented in Figure 3.12. The data, derived from Canada's Forest Inventory (Lowe et al. 1994), relate to timber-productive forests only and therefore concentrate on commercially important species, while other species and ecological attributes tend to be overlooked. As provincial and territorial forest inventories evolve, more attention is being given to these other attributes. However, the process is slow, and even current forest inventories provide only one-time status data. Trend information on forest change over time is difficult if not impossible to derive. At the moment, this inventory is Canada's only national forest vegetation database. Over the years, these data will serve as the baseline for indicators of ecosystem health and other values.

Box 3.5
The coastal temperate rain forest of the Pacific Maritime ecozone

Globally, coastal temperate rain forests are scarce, historically having covered more than 30–40 million hectares, or less than 0.2% of the Earth's land area. Their original extent included western North America and parts of New Zealand, Tasmania, Chile, and Argentina, as well as portions of Japan, northwest Europe, and the Black Sea coast of Turkey and Georgia (Kellogg 1992). Today, the largest undeveloped tracts of coastal temperate rain forests are found in South America and North America, and a very significant amount is in the Pacific Maritime ecozone.

Located in the lower-lying coastal areas, the coastal temperate rain forest is essentially a coastal Western Hemlock forest. This type of forest ecosystem covers 10.6 million hectares, or 54% of the land base of the Pacific Maritime ecozone. About 85% of it is actually forested, and 15% is naturally nonforested, consisting of wetlands and rock. This forest contains ecosystems with the highest biomass per hectare on Earth. Some 2.2 million hectares of this rain forest have been harvested since commercial logging first began 120 years ago (B.C. Ministry of Forests 1995).

About 52% of this forest is old growth. Since 1993, significant areas of old-growth rain forest, including the Kitlope, Upper Carmanah, and Walbran valleys and parts of Clayoquot Sound, have been protected. As of early 1995, the protected area totalled about 900 000 ha (8.4% of the total rain forest area). The creation of protected areas, however, is not sufficient to ensure the sustainability of old-growth ecosystems. To address this problem, improvements in the management of land lying between protected areas are being encouraged in British Columbia through the Forest Practices Code and Protected Areas Strategy as well as through recommendations arising out of the Clayoquot Sound Science Panel Report released in 1995.

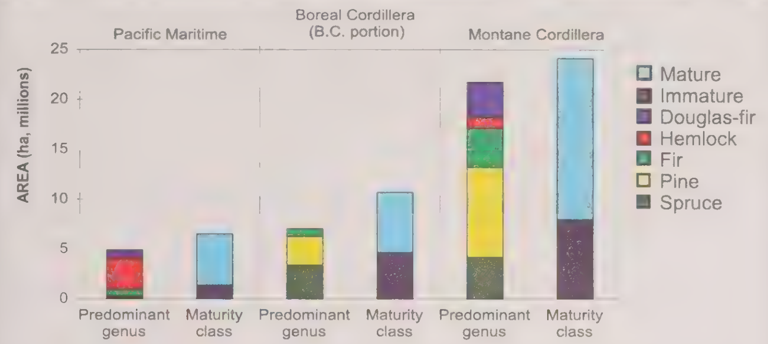
Old growth

Old-growth forests are characterized by mature trees, large amounts of fallen and standing dead wood, an often dense canopy, and structural diversity. However, the quantification of old growth is not straightforward. Within each ecological region, the old-growth stage of a forest may be reached at different ages, depending on the tree species and site conditions, and is characterized by unique ecological processes, plants, and animals. The determination of specific attributes, such as age-class, number of snags per hectare, and characteristic wildlife, must be tied to specific ecosystems (Duchesne 1994).

As Canada's Forest Inventory does not identify ecological attributes, currently the only practical way to quantify old growth at an ecozone level is to use the inventory's age-class data. Thus, Table 3.3 gives the relative distribution by ecozone of trees in the oldest age-class (over 120 years for Lodgepole Pine and deciduous species and over 140 years for all others). However, certain species may not be considered old growth even after 140 years. Species associated with the coastal Western Hemlock forest, as an example, tend to grow and mature well beyond this age. Nevertheless, considering the species and ecological conditions that predominate throughout the four terrestrial ecozones, these data generally provide a reasonable index of the proportion of older-growth forest in these areas.

Figure 3.12

Areal extent of predominant genera and maturity classes in timber-productive forests, 1991



Source: Canada's Forest Inventory, Petawawa National Forestry Institute.

Table 3.3

Area of older-growth forest, 1991

Ecozone	Area (ha, millions)			
	Older-growth[a]	Other forest[b]	Nonforested	Total area of ecozone
Pacific Maritime	6.0	4.0	9.5	19.5
Montane Cordillera	14.0	21.0	12.3	47.3
Boreal Cordillera	5.0	24.0	15.4	44.4

[a] Includes only the older-growth component of the timber-productive forestland.

[b] Total of non-timber-productive forestland and timber-productive forests not considered under Older-growth. Older-growth is considered as older than 140 years; for Lodgepole Pine and deciduous species, older than 120 years.

Source: Compiled using data from Canada's Forest Inventory, Petawawa National Forestry Institute.

Disturbance patterns

Natural and anthropogenic disturbances play critical roles in shaping forest ecosystems. Natural factors include fire, wind storms, frost damage, droughts, landslides, insects, disease, and the effects of animals. Human disturbances include logging, fire control, land clearing for urban development and agriculture, mineral development, and seismic exploration. However, pests, fire, and two anthropogenic disturbances — logging, including road building, and range management — account for the vast majority of area disturbed in these ecozones.

Generally, the coastal forests have a lower frequency of fire and biologically caused disturbance (insects and disease) than interior forests. However, coastal forests tend to have a higher rate of wind damage and water-related soil erosion. Most landslide and soil damage problems have been related to logging roads.

Fire

In the Taiga Cordillera and Boreal Cordillera ecozones, fire (Fig. 3.13) affects a far larger area than any other form of disturbance. Effective fire suppression in the Pacific Maritime and Montane Cordillera ecozones has reversed the dominance of natural fire regimes and resulted in significant decreases in the area lost to wildfires.

In some areas, however, fire suppression has put forests at greater risk from insects and disease. In the southern portion of the Montane Cordillera ecozone, for example, fire suppression has resulted in denser, older, and less vigorous stands, which are more susceptible to attack by the Mountain Pine Beetle. Another interesting side effect of reduced fire frequency can be found in some Yukon Lodgepole Pine stands. Here the reduced incidence of fire has actually resulted in an ecological shift to spruce trees, with thicker undergrowth and more mosses and needle litter. This additional material insulates the soil and allows the expansion of permafrost, which then excludes future growth by Lodgepole Pine (Oswald and Senyk 1977).

Insects and disease

Periodic insect outbreaks and diseases, such as root rot and white pine blister rust, are also significant factors in forest health and use. Since being introduced to British Columbia in nursery stock, blister rust, for instance, has seriously affected the use and management of Western White Pine as a commercial tree species. In outbreak years, insect damage (Fig. 3.14) can be the dominant disturbance in the Montane Cordillera. A significant portion of the harvest in British Columbia is directed towards salvaging logging areas with heavy infestation levels.

Within the Montane Cordillera ecozone, the Mountain Pine Beetle is the major pest of concern. Infestations from 1990 to 1993 were relatively low, covering less than 50 000 ha annually; in the 1980s, however, as many as 500 000 ha were infested. Spruce Budworm infestations also peaked in the late 1980s, with approximately 800 000 ha affected. Current infestations have been much smaller, covering 50 000 ha in 1993 and some 200 000 ha in 1994 (Canadian Council of Forest Ministers 1995).

Pest infestations within the Pacific Maritime ecozone are minimal. In the other ecozones, large forest areas may be attacked not only by the Spruce Budworm and the Mountain Pine Beetle but also by the Western Hemlock Looper and Forest Tent Caterpillar. The Asian Gypsy Moth remains a concern, primarily in urban areas, but Bt (*Bacillus thuringiensis*, a bacterial insecticide) has been effective, and a concerted effort to eradicate this pest is continuing (B.C. Ministry of Forests 1995).

Overall, insect and disease damage to B.C. forests is equivalent to approximately 25% of the annual allowable timber harvest. Some of this is due to severe or widespread outbreaks that could be prevented or reduced through various silvicultural procedures, including application of pesticides. Other damage from natural forest processes may have beneficial ecological side effects, however. The killing of old and weakened trees by Bark Beetles, for example, creates habitat for birds and animals and aids forest renewal and nutrient cycling (B.C. Ministry of Forests 1995).

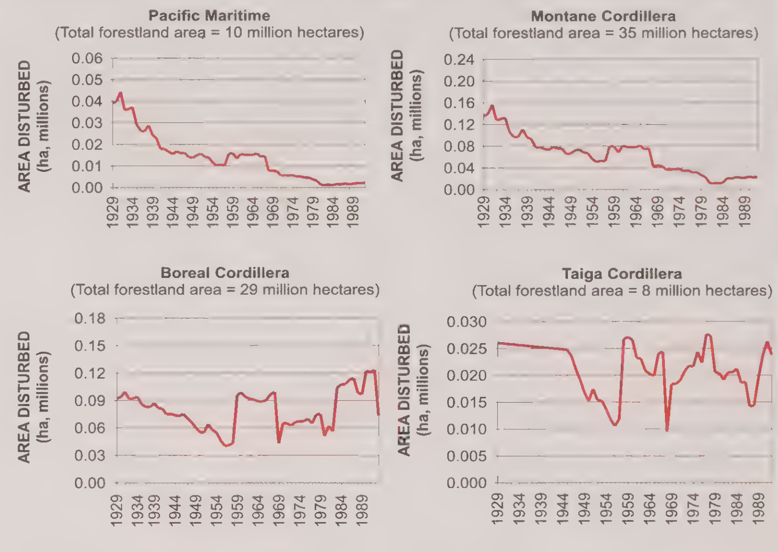
Harvesting

Harvesting has been increasing in importance as a forest disturbance since the 1920s (Fig. 3.15). While the area harvested in the rest of Canada doubled between 1920 and 1992 (see Chapter 11), harvested area tripled in the Pacific Maritime ecozone and increased 15-fold in the Montane Cordillera. In British Columbia, the harvested area peaked at roughly 260 000 ha in the late 1980s. The 1992–1993 harvest was approximately 210 000 ha, similar to 1984–1985 levels. The 1994–1995 Yukon harvest was approximately 2 100 ha, a fourfold increase over annual harvest rates of the preceding five years. Year-to-year fluctuations largely reflect market conditions.

In the Pacific Maritime ecozone, harvesting surpassed all other forms of forest disturbance in the 1950s and has had an increasingly significant impact. More intensive harvesting in this ecozone has also been coupled with increased fire suppression. Although the current area harvested is roughly equal to the area that would have burned naturally with no fire

Figure 3.13

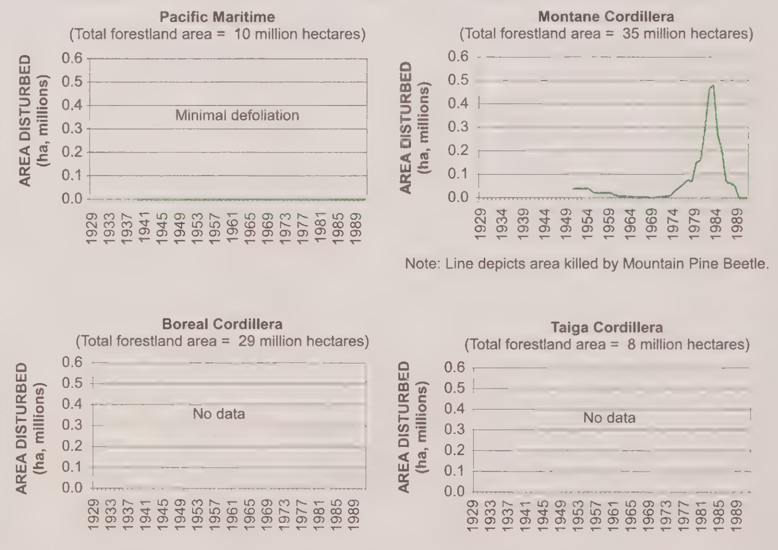
Area annually disturbed by fire (10-year averages), 1929–1992



Source: Essa Technologies Ltd. (1993); Canadian Forest Service, Natural Resources Canada, Ottawa.

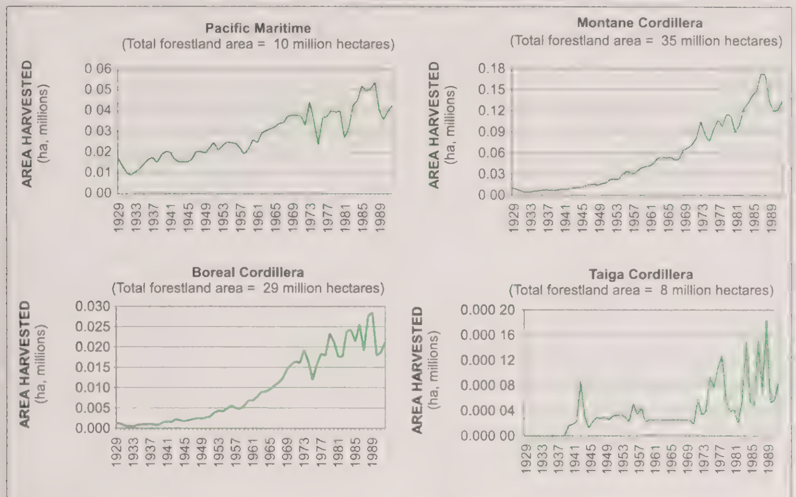
Figure 3.14

Area annually defoliated by insects, 1929–1992



Source: Essa Technologies Ltd. (1993); Canadian Forest Service, Natural Resources Canada, Ottawa.

Figure 3.15
Annual area harvested, 1929–1992



Source: Essa Technologies Ltd. (1993): Canadian Forest Service, Natural Resources Canada, Ottawa.

control, it is important to recognize that harvesting and forest fires are not ecologically similar disturbances. They differ in intensity, spatial size and location, remaining stand structure, and the resulting long-term dynamics of the affected ecosystems.

Cutting practices vary according to the particular forest and location, as well as its prime uses (e.g., recreation, lumber, and watershed protection) and the characteristics of the species being cut. Historically, clear-cutting — which involves harvesting all of the trees in an area at the same time — has been the predominant practice in these ecozones and the focus of considerable controversy. Clear-cutting is most often used with commercial species that require full sunlight for regeneration and good growth, such as Lodgepole Pine. When done without proper planning and engineering, any harvesting method can cause extensive soil erosion, stream sedimentation, reduced soil fertility, reduced biodiversity, and loss of soil nutrients. However, because clear-cutting has been the dominant forest practice, it has often been associated with poor forest management practices that led to ecological and aesthetic problems. Consequently, opinion is divided about the use of clear-cutting. Some authorities believe it is consistent with sound forestry practices, whereas others argue that it is incompatible with ecological sustainability.

Until recently, large clear-cuts were a common practice in these ecozones. Figure 3.16 shows the average cutblock sizes over six years for the interior and the coast of British Columbia. The interior roughly coincides with the Montane Cordillera and Boreal Cordillera ecozones; the coast roughly coincides with the Pacific Maritime ecozone. Over the six years shown here, the average cutblock size has decreased on the coast from 34 ha to 31 ha and in the interior from 46 ha to 35 ha. However, average cutblock size does not tell the whole story. In 1990, for example, although the average cutblock size for the interior was 41 ha and more than 78% of the area harvested was in blocks of less than 40 ha, 12% of the area harvested was in cutblocks of more than 80 ha (Canadian Pulp and Paper Association 1992).

New regulations are now causing loggers to take a closer look at the retention of stand structure. This will result in cutblocks that look different, with mature trees, including standing dead trees, retained within cutblock boundaries. The goal is not so much to reduce the size of the cutblocks as to retain important ecological characteristics, such as biodiversity, within them. High rates of cut, large cutblock size, and cutblock distribution are all factors in determining whether the resulting fragmentation will lead to loss of habitat and biodiversity (B.C. Ministry of Forests 1993).

Most reforestation in these ecozones occurs in British Columbia. Although the reforestation program has continued to grow since it started in 1930, the rate of reforestation has not kept pace with harvesting. Forest Renewal B.C., a Crown corporation formed in 1994, is working to enhance the productive capacity of provincial forestlands through improved reforestation, enhanced silvicultural practices, and intensive environmental cleanup (Forest Renewal B.C. 1995). Since 1987, all companies involved in logging have been required by law to replant the trees they cut and tend them until they are "free to grow." The creation of Forest Renewal B.C. should help meet this requirement.

British Columbia's reforestation program includes not only areas being harvested now but also those areas not successfully regenerated in the past. Currently, approximately 65% of the harvested areas in British Columbia are scheduled to be planted. The rest of the sites will restock naturally. The survival rate currently averages over 86% for two-year-old seedlings. In total, 19 different species are being used, and on many sites several species are planted. By law, only those species that are ecologically acceptable to the area can be planted.

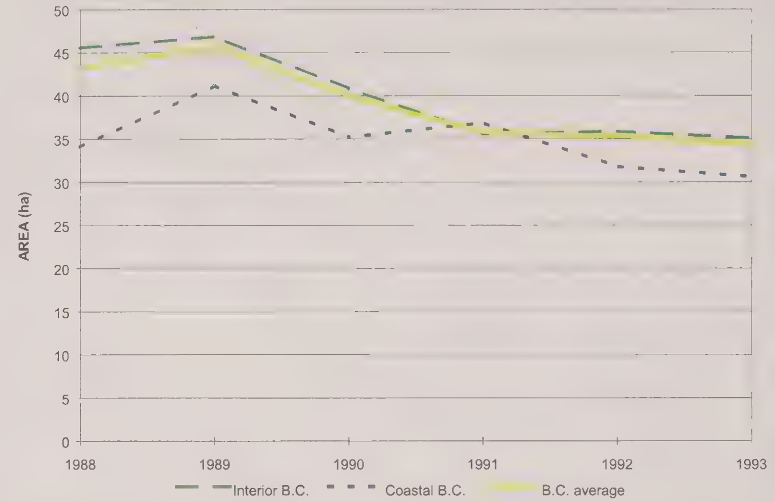
Prior to 1993, the Yukon relied on natural processes for regeneration of harvested areas. Of the approximately 4 600 ha harvested in total over the preceding five years, 622 ha have been replanted since 1993. Planting efforts are expected to continue to increase (Yukon Department of Renewable Resources and Environment Canada 1995).

Toxic Chemicals and the Food Chain

Toxic contaminants are present in all five ecozones and the freshwater, terrestrial, and marine ecosystems within them. For most ecozones, the majority of toxic contaminants come from human activities within the ecozones themselves. The contaminants of greatest concern are highly persistent substances that accumulate easily in living tissue and can harm the environment or cause serious human health problems such as cancer at very low concentrations (see Chapter 13). Examples include certain metals (such as lead, mercury, and cadmium), organochlorines (such as dioxins, furans, chlorophenols, polychlorinated biphenyls [PCBs], and some pesticides), and polycyclic aromatic hydrocarbons (PAHs). This section focuses on organochlorines because of their toxicity and presence throughout the five ecozones.

Figure 3.16

Average cutblock size in coastal and interior Crown land of British Columbia, 1988–1993



Source: B.C. Ministry of Forests (1995).

Sources and pathways of organochlorines

Sources of organochlorines may be local, regional, or distant. These compounds can be discharged in effluent from industries and municipal sewers or through sources such as air emissions, accidental spills, or the spraying of pesticides. Because of the persistence of these chemicals, fields and drainage systems that were sprayed many years ago may still be a source of organochlorines to the world's atmosphere.

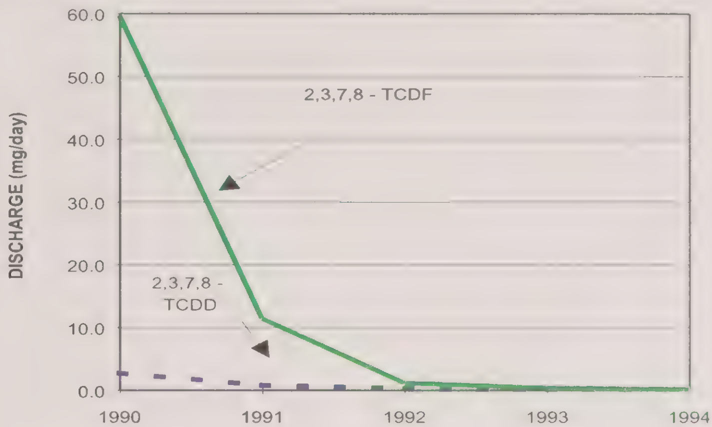
Industries have been a major source of organochlorines in the Pacific Maritime and Montane Cordillera ecozones. Among the chemicals that have caused the most concern are pentachlorophenol, a sapstain control agent once used by many sawmills, particularly in the Georgia Basin, and PCBs, formerly used in hydraulic fluids, electrical transformers, and a wide variety of other products. The use of both of these substances has been virtually eliminated in British Columbia (although older transformers containing PCBs are still in use). PCBs are not very soluble in water and tend to end up in sediments. In nonindustrial areas, sediments generally have PCB concentrations ranging from nondetectable to about 0.1 parts per million (ppm). Although concentrations are quite variable, higher levels in sediments have been observed in areas around some industrial sites in British Columbia and in a number of harbours, including Victoria and Vancouver, where concentrations have ranged from 2.2 to 17.0 ppm (Wells and Rolston 1991).

Dioxins and furans have also been the focus of a great deal of concern. They are formed as by-products of combustion processes (in sources such as incinerators and power boilers) or chemical processes (such as those in kraft pulp mills). They may also be present as contaminants in chemicals such as PCBs and pentachlorophenol. Because dioxins and furans can be highly toxic, the 17 pulp and paper mills that use chlorine bleaching processes in this part of Canada have recently received the most attention of any industrial effluent dischargers.

Pulp mill effluent contains well over 300 different individual chlorinated organic compounds. Since 1987, samples of sediments, fish, invertebrates, and mammals have been obtained near pulp mills and analyzed for dioxins and furans. Some oyster, crab, and fish samples have been found to be near or well above the Health Canada guideline of 20 parts per trillion (ppt) for muscle tissue. Concerns for people who might eat contaminated seafood and freshwater fish have prompted dioxin-related closures of fisheries as well as the announcement of consumption advisories in Kitimat Harbour and other places along the B.C. coast and on sections of major rivers such as the Fraser, Thompson, and Columbia. As of early 1995, 120 000 km^2 of coastal area had been closed to harvesting of certain species of shellfish because of toxic contamination. Most of these areas are associated with pulp mills, but some are in the vicinity of sawmills that formerly used pentachlorophenol.

As a result of new federal and provincial controls on pulp mill discharges, some B.C. rivers and coastal areas are now

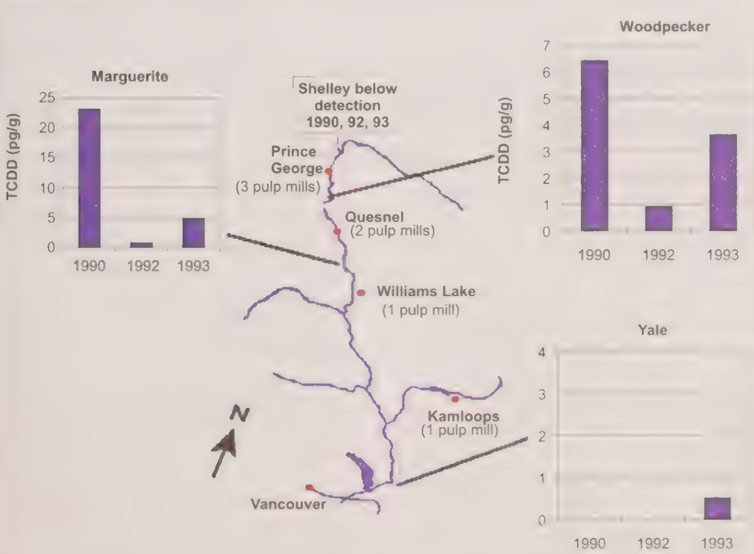
Figure 3.17
Average daily discharge of TCDD and TCDF to the Columbia River by Celgar Pulp Co., 1990–1994



Note: TCDD and TCDF have not been detected in Celgar Pulp Co. effluent since July 1993.

Source: B.C. Ministry of Environment, Lands and Parks (1995a).

Figure 3.18
TCDD concentrations in suspended sediments collected from the Fraser River, 1990–1993



Source: 1990 data from Derksen and Mitchell (1995); 1992, 1993 data from Sekela et al. (1995).

clearly in the process of recovery. By 1994, following modifications to pulping and bleaching processes, average daily discharges of AOX (organochlorines and other adsorbable organic halogens) from B.C. pulp mills fell by 56% from 1991 levels. Between 1988 and 1994, the average reduction in AOX discharge was 81% (B.C. Ministry of Environment, Lands and Parks 1995a). From 1991 to 1994, kraft mills in the Montane Cordillera ecozone reduced average AOX discharges by 82%, on average, compared with an average reduction of 40% at mills in the Pacific Maritime ecozone.

Discharges of dioxins and furans into the Columbia River have also been substantially reduced. Between 1990 and 1994, average daily pulp mill discharges of the most toxic dioxin (2,3,7,8-TCDD) declined by almost 93%, while those of the most toxic furan (2,3,7,8-TCDF) decreased by over 99% (Fig. 3.17) (B.C. Ministry of Environment, Lands and Parks 1995a).

Because contaminants can be transported with suspended sediments, persistent chemicals, such as organochlorines, may later end up being redeposited in places such as the Fraser estuary or Strait of Georgia. In the Fraser River suspended sediment sampling program, dioxin and furan concentrations have been measured in sediments at four sites. The Shelley site (above Prince George) serves as a control station, as it is upstream of all pulp mills. The Woodpecker station is downstream of the three mills at Prince George, and the Marguerite station is downstream of the two Quesnel mills. The Yale station is the farthest downstream of the four sites and is not situated close to any pulp mills. Laboratory results show that suspended sediment concentrations of both 2,3,7,8-TCDD (Fig. 3.18) and 2,3,7,8-TCDF have declined since the fall of 1990.

Dioxins and furans in biota

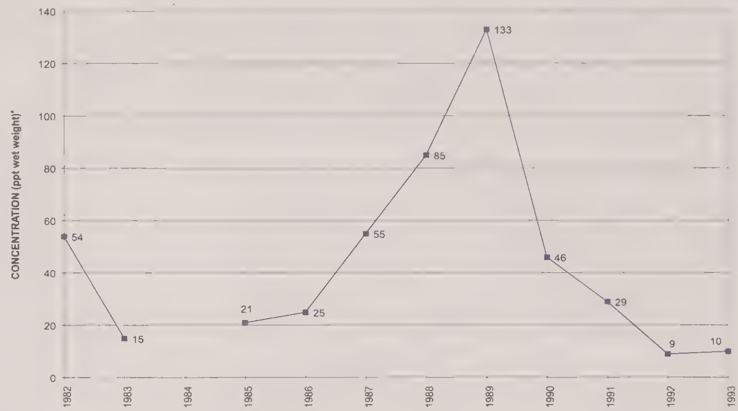
Since 1988, dioxin-related fish consumption advisories have been issued for the Fraser, Thompson, Quesnel, North Thompson, and South Thompson rivers. Some sportfish and fish that are an important part of Native peoples' traditional diet have been included in these advisories. Recently, significant reductions in contaminant concentrations have been measured in fish samples from some of these areas. Between 1990–1991 and 1994, for example, TCDD levels in Mountain Whitefish taken from several locations in the Columbia River dropped by 47–87%. During the same period, TCDF levels fell by 77–93%. As a result, certain areas have been reopened and some advisories lifted (B.C. Ministry of Environment, Lands and Parks 1995a).

The fish data (B.C. Ministry of Environment, Lands and Parks 1995a) reveal several interesting and potentially important patterns. First, dioxin and furan levels in whitefish seem to be highest immediately below the pulp mills and lower at sites farther downriver. Second, at all sites, whitefish dioxin and furan levels were lower in 1994 than in 1990–1991. Third, the rate of decline of furan concentrations in whitefish and juvenile Chinook Salmon seems to be greater than for dioxin. This is consistent with the hypothesis that dioxins are more persistent in the environment than furans. Finally, the decline in dioxin levels in Columbia River Mountain Whitefish may indicate a fairly rapid cleansing of these substances from the food chain following process changes in the mills. However, environmental monitoring continues.

Great Blue Heron and Double-crested Cormorant eggs are also valuable indicators of the presence of persistent contaminants, such as dioxins and furans, in the environment. In the late 1980s, dioxin levels in eggs of Double-crested Cormorants from the Strait of Georgia were higher than levels in similar eggs from the Bay of Fundy, the St. Lawrence estuary, and Lake Ontario. Studies have shown that elevated levels of dioxin in heron eggs are associated with negative effects on developing embryos (Bellward et al. 1990; Hart et al. 1991; Whitehead et al. 1992). More recently, dioxin concentrations in heron and cormorant eggs from the Strait of Georgia have declined considerably, in some cases by more than 95% (Fig. 3.19).

Figure 3.19

Dioxin concentrations in Great Blue Heron eggs collected near the University of British Columbia, 1982–1993



[a] Geometric means.

Source: Canadian Wildlife Service, Pacific and Yukon Region, Environment Canada.

Two complementary factors may have contributed to the decline — first, the reduction or virtual elimination of dioxins and furans from effluent discharged into marine and fresh waters by pulp mills, and second, the elimination of chlorophenols for sapstain control by the B.C. lumber industry. The decline in dioxin levels in the eggs of herons and cormorants also indicates a rapid cleansing of these substances from the food chain (P.E. Whitehead, personal communication).

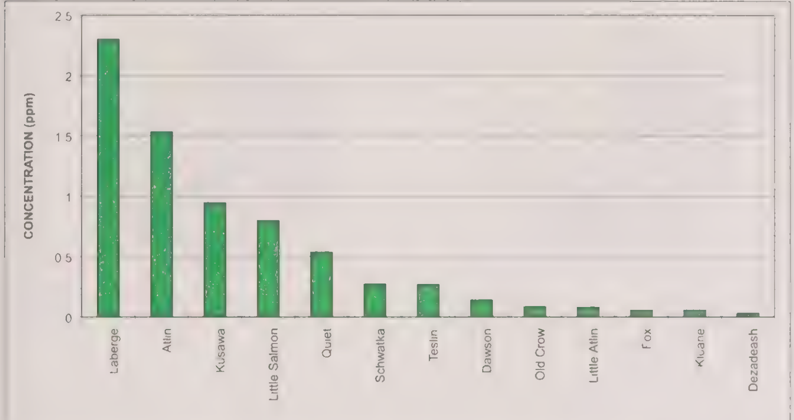
Organochlorines in remote environments

Problems of toxic contamination are by no means limited to areas near industrial sources such as pulp mills. In 1990, tests of fish from Lake Laberge, on the Yukon River downstream from Whitehorse, revealed surprisingly high levels of toxaphene (an organochlorine pesticide), as well as PCBs in some specimens. As a result, Health and Welfare Canada advised Yukoners to limit consumption of the livers of Burbot and the flesh of Lake Trout from the lake. The small commercial fishery in the lake closed, and the non-Native domestic food fishery was reduced.

Similar levels of toxaphene were found in the livers of Burbot from Atlin Lake, also in the Boreal Cordillera, and an advisory recommending restricted consumption of Burbot livers was issued in 1992. Studies of fish from other lakes and rivers detected low levels of organochlorines, mostly toxaphene, in samples from most locations (Fig. 3.20). Concentrations varied greatly from species to species, with fish that are low in fat, such as Northern Pike, and fish feeding on invertebrates, such as Arctic Grayling and whitefish, having very low or nonmeasurable levels of toxaphene.

Toxaphene levels in each species of fish also varied from lake to lake. Research indicates that this variation is related to differences in the food webs of the lake and perhaps also to differences in climate

Figure 3.20
Toxaphene levels in livers of Burbot from lakes and rivers in the Boreal Cordillera ecozone, 1990–1993



Source: Yukon Department of Renewable Resources and Environment Canada (1995).

and in the physical and chemical properties of the lakes.

Toxaphene was once widely used in the southern United States, Mexico, Central America, and Asia. Although now banned in Canada and the United States, it is still in use in some parts of the world. In British Columbia and the Yukon, it was previously used to kill undesirable fish species in lake-stocking programs. However, the current distribution and levels of toxaphene in fish cannot be explained by these limited past uses (Kidd et al. 1993). Instead, evidence from air, water, and sediment studies indicates that toxaphene reaches local ecosystems through the air, probably from distant sources in North America and Asia (Yukon Department of Renewable Resources and Environment Canada 1995).

Within the four terrestrial ecozones, low levels of organochlorines have been detected not only in the north but in other remote areas, such as the Mt. Robson and Kananaskis parks along the Continental Divide of Alberta and British Columbia. It is not clear yet whether concentrations of toxic substances in any of these areas are increasing or decreasing.

FRESH WATER

Overall, the four terrestrial ecozones have an abundance of clean, fresh surface water and groundwater. Both water supplies and water quality appear to be good. There are, however, reasons for localized concerns.

Supply and use

There is some evidence of long-term changes in water supplies. Data from around the region suggest decreasing average annual stream flows at more southerly sites and increasing flows at some northern B.C. sites (Leith 1991). Similar trends have been observed in snowpack water storage. However, only 5 of the 17 stream flow stations and 4 of the 11 snowpack monitoring stations showed statistically significant trends. Climate models suggest that global warming may further exacerbate this situation by significantly reducing summer precipitation in southern parts of British Columbia while increasing summer evapotranspiration.

Municipal water demand peaks at different seasons in the north and south. In the north, it is typically highest in winter because of bleeding — the continuous running of water through pipes to keep them from freezing (Fig. 3.21). In Whitehorse, bleeders are common in older homes, although newer homes are required to use electrical heating devices. When the use of water bleeders and the high rate of leakage of treated water from the city's water delivery system are taken into account, the consumption of water by Whitehorse residents is similar to that of other Canadian cities.

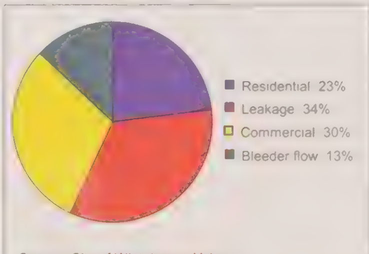
Overall, the main water use in the Yukon is placer mining. In 1993, approximately 77% of water allocated through the Yukon Territorial Water Board was for placer mining, about 10% was for hard rock mining, and about 5% was for municipal use.

In the southern ecozones, residential consumers are the largest users of water (Fig. 3.22). Demand is typically highest in the summer. Unfortunately, this is also the time of year when precipitation is lowest. Seasonal shortages in domestic supplies have been reported for some time, particularly in southern parts of the Montane Cordillera ecozone (e.g., in the Kootenay, Cariboo, and Thompson–Okanagan regions) and the Pacific Maritime ecozone (e.g., the Central Coast and Sunshine Coast regions). In the summer of 1992, both Vancouver and Victoria experienced water shortages and rationing.

Sewage treatment

There are currently 72 secondary and 10 tertiary treatment plants discharging to fresh waters within British Columbia and the Yukon. Altogether, 31% of the B.C.

Figure 3.21
Total water use in Whitehorse, 1993

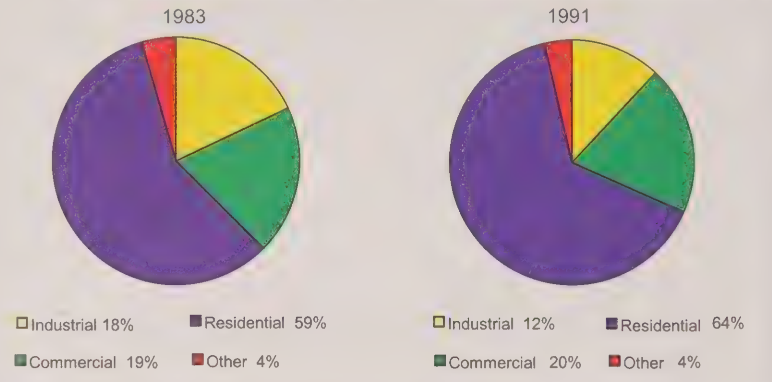


Source. City of Whitehorse, Yukon

population and 15% of the Yukon population are served by either secondary or tertiary treatment. In the Yukon, 60% of the population have only primary sewage treatment, and 25% rely on septic fields, holding tanks, or other systems. In British Columbia, six primary treatment facilities still discharge to fresh waters, and the two largest serve the Vancouver area. Plans are under way to upgrade these to secondary treatment.

In the north, the use of bleeders makes sewage more difficult to treat. In Whitehorse, for example, the sewage system can no longer handle the volume of water discharged to the city's sewers. To correct this problem, larger sewage lagoons are being constructed, and the city is promoting water conservation, including the reduction of bleeding.

Figure 3.22
Municipal water use in British Columbia, 1983 and 1991



Source: Municipal Water Use Database, Environment Canada, Ottawa.

Drinking water

Surface waters supply more than half the municipal waterworks in British Columbia, serving 85% of the population. In all, about 300 communities in British Columbia and the Yukon rely on surface water sources for drinking water. However, of the population living outside of Whitehorse, Greater Victoria, and Greater Vancouver, half receive their drinking water from groundwater supplies.

The occurrence of toxic chemical contaminants in drinking water is a potential concern. However, a study of drinking water from B.C. communities near pulp mills on the upper Fraser and Thompson rivers showed no evidence of dioxin, furan, or other organochlorine contamination (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993).

Overall, microbiological contamination is the greatest threat to drinking water quality within these ecozones. The incidence of intestinal infections is much higher than in the rest of Canada and has generally been increasing over the past eight years for reasons yet unknown. Since 1980, there have been more than 16 outbreaks of waterborne diseases in this part of Canada. Well over half were due to giardiasis, a parasitic disease commonly known as "beaver fever." Another parasite, *Cryptosporidium*, is known to occur as far north as Whitehorse (Roach et al. 1993), although it is a less common cause of waterborne disease.

Most water requires only a minimal level of treatment, such as chlorination, to meet Guidelines for Canadian Drinking Water Quality. In 1992, compliance with bacterial standards became a legislated requirement in British Columbia. Five B.C. communities currently take water treatment beyond chlorination (Crippen Consultants 1990).

Acid rock drainage

Acid rock drainage (ARD) occurs when sulphides in rock are exposed to air and water to form sulphuric acid. The release of metals that results from acidification of the local environment can severely damage aquatic ecosystems. Mines are one of the most common sources of ARD.

In the Yukon, there are currently no operating mines, but Faro (reopening in 1995) alone has 55 million tonnes of acid-generating tailings and 100–150 million tonnes of waste rock, much of which is acid generating or may become acid generating. In British Columbia, none of the eight operating coal mines is currently generating ARD. Of the 16 operating metal mines, 6 generate ARD, and several others have the potential to do so. The six that are currently generating ARD are collecting and treating all acidic drainage. There are approximately 72 million tonnes of acid-generating mine tailings and 250 million tonnes of acid-generating waste rock in British Columbia. This amount is increasing by 25 million tonnes per year (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993).

Good planning can prevent or minimize ARD in new mining developments. However, a larger problem is that ARD can persist for hundreds of years at closed and abandoned mine sites. In the Yukon, there are many closed mines, some of which generate ARD. Coal mines within these ecozones, unlike those in other regions, do not generate ARD, but some lead–zinc–gold mines do. In British Columbia, at least five abandoned mines are known to be generating ARD. Remediation is under way at a number of abandoned sites, including the Mt. Washington mine on Vancouver Island.

Surface water quality

Water quality varies naturally by place and season, but much of the information about it is related to specific human activities or to particular problems that need to be solved. Consequently, there is only a limit-

ed amount of information from which to draw region-wide conclusions about water quality. To collect long-term data suitable for detecting regional trends, governments in this region began a cooperative water quality monitoring program in 1985. However, because of natural variability, detecting trends typically requires at least five years — and sometimes more than a decade — of consistent data.

Physical and chemical data for the Flathead and Similkameen rivers in British Columbia showed no trends during 1985–1990, except increasing ambient air temperatures and water temperatures in both rivers and declining stream flows in the Flathead River. These trends are attributed to fluctuations in weather (Shaw and Taylor 1994). No trends were detected in the Columbia River at Revelstoke for 1985–1993 (C. MacLeod and P.H. Whitfield, unpublished data), nor in the Skeena River at Usk for 1985–1992 (I. Bhangu and P.H. Whitfield, unpublished data). An interim assessment of the 1984–1989 data from six small lakes in southwestern British Columbia that are exposed to atmospheric pollutants gave no indication of acidification (Swain et al. 1994). However, this conclusion will be reexamined using 10 years of data from 1984 to 1994.

Groundwater quality

Groundwater extraction is regulated only for major users in the Yukon and British Columbia. Consequently, there are few data regarding trends in use. Because extraction is largely unregulated, groundwater is also not priced, except to the extent that users must pay the actual cost of developing the resource. Threats to quality and quantity of groundwater are several: contamination from fertilizers and pesticides, saltwater intrusion from excessive withdrawal in coastal areas, and poor well construction practices. The largest groundwater user in this part of Canada is industry, followed by agriculture, municipalities (composed of domestic, commercial, and industrial urban users), and rural domestic users.

Contamination of groundwater with nitrates can result from agricultural activities (e.g., fertilizer overapplication and manure stockpiling) and land disposal of domestic sewage effluent. Nitrates reduce the ability of blood to carry oxygen, and infants and expectant women are particularly at risk from drinking well water with high nitrate concentrations. Several areas in the southern portions of the Pacific Maritime and Montane Cordillera ecozones have contaminated aquifers in which nitrate levels exceed the Canadian drinking water quality guideline for nitrate (Groundwater Section, B.C. Ministry of Environment, Lands and Parks, unpublished data). Agricultural activities are also a source of pesticides, which have been detected in a number of aquifers.

One of the most important of the contaminated groundwater systems is the Abbotsford aquifer, which is an important source of water for the Lower Mainland and the state of Washington. Because it is exposed to the land surface, it is particularly vulnerable to contamination from land use. Nitrate contamination — mostly from the improper storage and application of chicken manure — is of concern, and nitrate levels in some areas are more than four times greater than the Canadian drinking water quality guideline of 10 ppm. In addition, concentrations of four pesticides exceed either Canadian or U.S. Environmental Protection Agency guidelines, although the health implications of these concentrations are not well understood.

Pacific Marine Environment

Although the Pacific Marine ecozone extends well beyond the continental shelf into the Pacific Ocean, most of the available information about environmental conditions relates to the area over the continental shelf and, in particular, to the Strait of Georgia, Puget Sound, and Juan de Fuca Strait (Marine Science Panel 1994; Wilson et al. 1994).

Human activities

Human activities have a substantial impact on the marine environment, especially in the Strait of Georgia and Juan de

Figure 3.23
Significant marine spills, 1972–1993

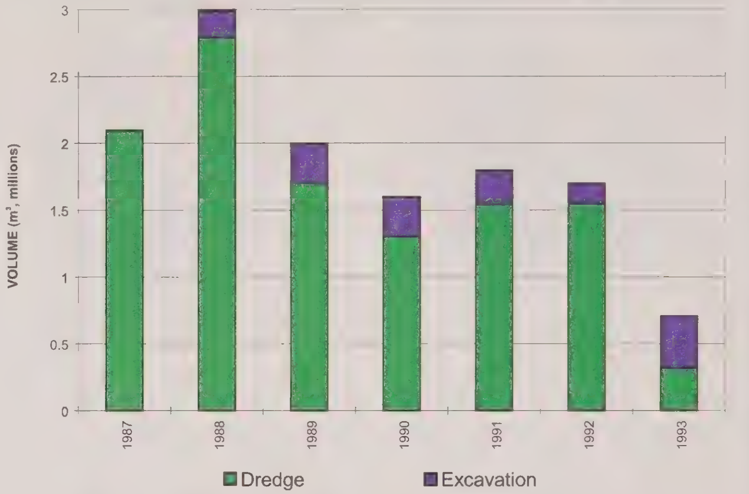
Source: Spill Tracker Database, Emergencies Section, Environmental Protection Branch, Pacific and Yukon Region, Environment Canada.

Fuca Strait; as the area's population grows, the potential for damage to the marine environment increases. Debris such as discarded fishing gear and plastic objects kills hundreds of marine mammals and thousands of seabirds every year (see Chapter 10), whereas foreshore development alters or destroys important rearing, feeding, and spawning habitats. In addition, industrial and domestic effluent discharges contaminate water, sediment, and biota and pose a threat to human health.

As ship traffic increases, so does the risk of a major oil spill. Significant spills (those exceeding 1 t or affecting sensitive habitats) decreased substantially after 1975 (Fig. 3.23), largely because of changes in tanker design, stiffer penalties for violations, and improved traffic management. However, the number of spills has been increasing since 1975. Overall, significant spills make up approximately 5% of all spills reported. Recent changes to U.S. legislation, imposing stricter conditions on tankers carrying oil between Washington and Alaska, may cause more of these ships to use the more protected waters of the Inside Passage, thus increasing the risk of significant spills in Canadian waters (A. Hillyer, West Coast Environmental Law Association, personal communication).

There are 20 active ocean disposal sites in this ecozone, and all material destined for disposal (mostly dredging and excavation spoils) must meet stringent government guidelines. The total amount of waste disposed of at these sites has declined considerably since 1988 (Fig. 3.24), mainly because of reductions in economic activity, fluctuations in sediment loading from the Fraser River, and changes in the availability of landfill sites. Monitoring of active dump sites shows no evidence of unacceptable contaminant levels (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993).

Figure 3.24
Amount of waste disposed of at designated ocean disposal sites, 1987–1993



Source: Ocean Disposal Control Program, Environmental Protection Service, Pacific and Yukon Region, Environment Canada.

Fish and wildlife habitat changes

Historically, the draining of wetlands and the diking of tidal marshes to create agricultural and, later, urban land have had a formidable impact on nearshore aquatic habitats. More than 50% of the riparian habitat and 80% of the salt-marsh habitats in the Fraser River estuary and lower river have been lost in this manner (Levings and Thom 1994). In addition, about 18% of intertidal marsh along the Strait of Georgia coastal areas has been lost since the turn of the century. The most extensive losses of marshes and estuaries are near heavily populated areas, such as Burrard Inlet (130 ha or 93% loss), the Cowichan River (89 ha or 54% loss), and the Nanaimo River (145 ha or 54% loss) (Hutchinson et al. 1989).

Today there is continuing pressure on these nearshore marine habitats and wetlands from foreshore development, dredging, and log storage. The cumulative effect of these small-scale losses on marine plant and animal communities is considerable and often irreversible.

Important wetland habitats for fish and other wildlife have been protected through acquisition by the Pacific Estuary Conservation Program. The program, supported by The Nature Trust of British Columbia, Ducks Unlimited Canada, Wildlife Habitat Canada, and the provincial and federal governments, has acquired approximately 900 ha of estuarine habitat in the Strait of Georgia. Some provincial marine parks and ecological reserves in the Strait of Georgia and Juan de Fuca Strait also include intertidal and subtidal areas. Marine ecosystems are poorly represented, with less than 2% of British Columbia's marine waters under some form of protection (B.C. Ministry of Environment, Lands and Parks 1995b). Most of these protected areas do not conserve marine biota, and recreational and commercial harvesting are permitted.

Contaminants

The major contaminants of concern include PAHs, dioxins and furans, and nutrients. Concentrations of PAHs in surface sediments in the Strait of Georgia have been decreasing since the 1950s, probably because of the decline in the domestic use of coal (Macdonald and Crecelius 1994). However, elevated concentrations of a number of other toxic organic compounds have been measured in harbours near Victoria and in Vancouver Harbour, where toxic effects on benthic animals and fish are evident. In Port

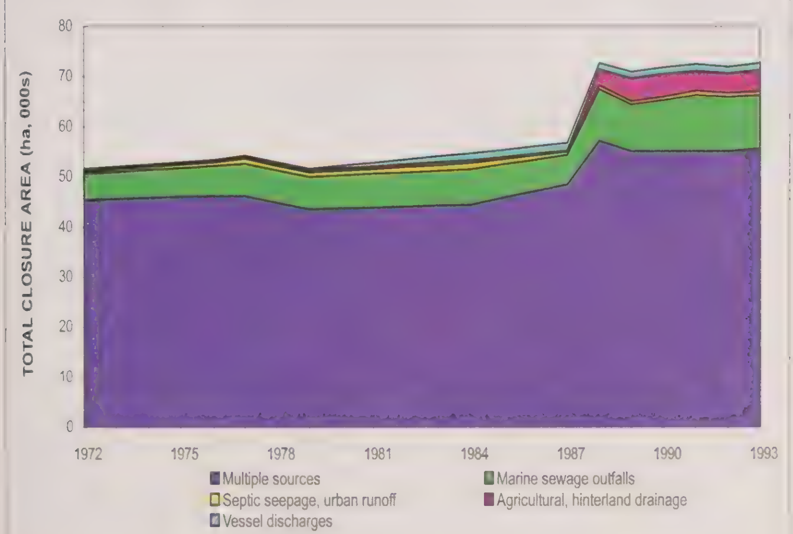
Moody Arm at the eastern end of Burrard Inlet, where several industrial dischargers (including oil refineries) are located, up to 75% of the adult English Sole show liver lesions (Goyette 1994). These lesions have been linked primarily to sediment PAHs (Goyette 1994; Johnson et al. 1994).

Dioxins and furans have been measured in sediments and some biota in marine waters adjacent to pulp mills, but most fish samples show no detectable concentrations. However, some samples of oysters and crabs have exceeded the guidelines for human consumption. This has led to harvest closures or consumption advisories for shellfish in these areas. Dioxins measured in sediment cores from Howe Sound and the Strait of Georgia have shown a general decrease since the mid-1970s, following the installation of emission controls on plastic-burning incinerators. Sediment concentrations are now generally much lower than in the more populated and industrialized areas of Puget Sound (Macdonald and Crecelius 1994).

The main human sources of nutrients, such as nitrogen compounds and phosphates, are sewage and agricultural runoff. Too many nutrients may cause eutrophication (excessive biological production), with resulting harmful effects on many species. The severity of these effects depends, however, on the naturally occurring supply of nutrients from rivers and the ocean itself. Fortunately, nitrogen concentrations in the Georgia Basin are always high because of winds, tides, currents, estuary mixing, and the upwelling of nutrient-rich, deep ocean water. In fact, oceanographers estimate that roughly 10 times more nitrogen comes from ocean upwelling than from the Fraser River and sewage (Harrison et al. 1994).

Eutrophication is inhibited by poor light and strong currents, which vigorously mix and flush the sewage nutrients, especially in coastal waters off Victoria in Juan de Fuca Strait. As a result, added nitrogen from human sources produces only a minor increase in algal growth. To the south in Puget Sound, where bays and inlets are poorly flushed, the situation is different, and signs of eutrophication, such as low oxygen and high chlorophyll, are evident. Scientists recommend that similar waters in Canada — particularly those, such as Boundary Bay, Burrard Inlet, Sechelt Inlet, and Saanich Inlet, that are near large urban centres — be more closely monitored to detect early signs of eutrophication (Harrison et al. 1994).

Figure 3.25
Sanitary closures of shellfish fisheries, 1972–1993



Source: Shellfish Program Closure Database, Shellfish Section, Environmental Protection Service, Pacific and Yukon Region, Environment Canada.

Risks to human health

The primary risk to human health in the Pacific Marine ecozone comes from the contamination of seafood, such as clams, oysters, and crabs, by bacteria, viruses, and toxic chemicals. Shellfish closures (as discussed above) provide a useful indicator for tracking the contamination of these organisms. Some closures are due to the natural occurrence of red tide, an infestation of toxic plankton that is fatal to many forms of marine life. However, various pollution sources, such as agricultural runoff, boat sewage, urban runoff, and septic seepage, account for the largest area of closures, with municipal sewage discharges being the largest single source. Closures have also occurred as a result of dioxin and furan contamination.

Sanitary closures of shellfish habitat have increased steadily since 1972. As of 1993, there were about 180 such closures, encompassing 73 000 ha of coastline (Fig. 3.25). This increase is not due solely to an increase in sampling effort but reflects an actual worsening of the problem. The number of closure actions per year has also increased, from 12 in 1991 and 15 in 1992 to more than 20 in 1993. During the same three-year period, only three closures were revoked and three were reduced. In 1994, 81% of the total closures were in the Georgia and Juan de Fuca straits. These closures resulted in serious hardship to many people who depend on a healthy fishery for their livelihood or their own consumption.

Commercial and recreational harvest closures of some species of shellfish due to dioxins and furans increased in February 1995 to 120 200 ha of coastal marine habi-

tat, up from almost 90 000 ha in May 1992 (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993) and 113 700 ha in August 1993. However, those increases were due to extensions of existing closures and have arisen primarily from an expanded sampling program rather than from increased levels of dioxins and furans. More recently, owing to declines in dioxin and furan contamination reported in August 1995, 48 650 ha of shellfish habitat were reopened (S. Samis, Department of Fisheries and Oceans, personal communication). This represents a lifting of crab hepatopancreas consumption advisories from 40% of the area previously affected.

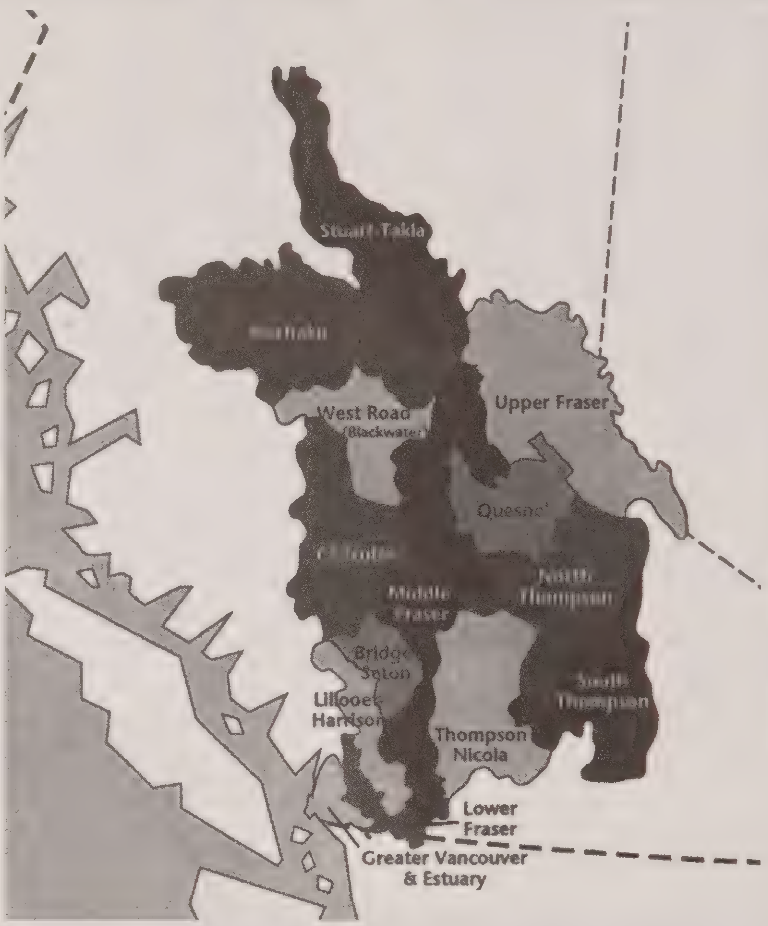
Sustaining the Fraser River Basin

The Fraser River Basin is the fifth largest river basin in Canada (234 000 km²) and drains nearly one-quarter of British Columbia (Fig. 3.26). Composed of more than 13 subbasins, this vast drainage area spans the Montane Cordillera and Pacific Maritime ecozones and includes numerous tributaries, streams, and lakes.

The Fraser Basin is internationally recognized for its ecological diversity. The river is the greatest producer of salmon of any in the world (Northcote and Larkin 1989) and contains a wide diversity of native fish species. Equally significant, 21 species of waterfowl breed here, making it one of the most diverse waterfowl communities in Canada. The Fraser River estuary, located at the mouth of the Fraser where it discharges into the Strait of Georgia, contains some of the most productive wildlife habitat in western North America. Located on the Pacific Flyway, the Strait of Georgia is a major stopover for birds migrating from eastern Siberia and western North America to South America.

The Fraser is also the main artery of British Columbia's resource-based economy, supporting a wide variety of farming activities as well as forestry and mining. It is a key attraction for the recreation and tourist industries as well. In addition to housing and employing two-thirds of the province's population, the basin accounts for about 75% of its value-added manufacturing. The river's commercial, recreational, and Native salmon fisheries alone generate an annual landed value of $300 million. It is a river in which the environment and the economy are inextricably intertwined. To ensure that it is used sustainably, the federal government launched a major initiative in 1991 — the Fraser River Action Plan (FRAP) (Box 3.6).

Figure 3.26
The Fraser River Basin



The Fraser Basin has changed dramatically over the past century, mostly because of population growth and resource development. As these pressures continue and intensify, many local and regional problems have emerged. Among the most important of these are concerns about water quality, wildfowl habitat, and the salmon fishery.

Drinkable, swimmable, and useable?

Although water quality in the basin is good in comparison with that of other drainage basins in Canada, such as the Lower Great Lakes and the St. Lawrence River (Hall et al. 1991), it is degraded by wastewater and other contaminants at

several locations between the upper reaches at Prince George and Quesnel and the mouth (Servizi 1989). Over half the industrial discharges in the basin come from interior pulp mills, whereas over 90% of municipal waste discharges occur in the lower Fraser Basin. In all, the average total discharge of all municipal, industrial, and agricultural wastewaters into the Fraser River estuary is estimated to be 908 million cubic metres annually (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993). Groundwater is not immune from damage either. The Abbotsford aquifer, as already noted, faces problems of nitrate and pesticide contamination, largely from agricultural sources.

Although there has been a substantial increase in the number of communities with tertiary sewage treatment, the largest waste producer, the Vancouver metropolitan area, is not yet among them. Consequently, most waste entering the basin's receiving waters still receives only primary treatment. Furthermore, discharges are increasing rapidly, with flows from the Annacis sewage treatment plant expected to double by 2036 as the eastern part of the Lower Mainland region grows (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993). In 1985, more than half of the bioassays at the Annacis and Lulu plants showed toxicity to fish. At the Iona sewage treatment plant, problems with fish kills and highly contaminated sediments led to the installation of a deep-water effluent discharge 2 km offshore. No major impacts have been identified since. Coliform counts at Vancouver area beaches have also decreased (Greater Vancouver Regional District 1992; B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993).

Some sewage treatment plants, such as those at Annacis and Prince George, are now being upgraded to partial or full secondary treatment. There has also been a move by federal and provincial environmental agencies towards setting water quality objectives that are adapted to specific bodies of water or aquifers. While the objectives are not legally enforceable, they do form a reference point for judging water quality at a particular site. Water quality objectives have been set for several of the large river sections in the basin, including the lower Fraser River, the Thompson River, the Nechako River, and the upper Fraser River from Hope to the headwaters. However, the lack of legally enforceable standards remains a major obstacle in accelerating the improvement of water quality.

Box 3.6
The Fraser River Action Plan (FRAP)

Recognizing the need to safeguard the Fraser River Basin ecosystem, which is of national and international significance, the federal ministers of the Environment and of Fisheries and Oceans established the Fraser River Action Plan (FRAP) in 1991. The key goals of this multiyear program are to reduce pollution, to improve fish and wildlife productivity, and to work with partners and stakeholders to develop a strategy that ensures the Fraser Basin is managed for sustainability.

FRAP is a jointly structured initiative, with each federal department bringing its own expertise and emphasis to the action plan. The Department of Fisheries and Oceans is concerned primarily with rebuilding salmon stocks and restoring fish habitat, whereas Environment Canada focuses on protecting wildlife habitat, assessing environmental quality, and reducing pollution. Progress towards FRAP goals has been documented in the 1991–1994 midterm report (Environment Canada and Department of Fisheries and Oceans 1994) and in subsequent reports by the sponsoring departments (Environment Canada 1995; Environment Canada and Department of Fisheries and Oceans 1995).

To meet the goal of building partnerships and developing a strategy for sustainability, Environment Canada and the Department of Fisheries and Oceans, along with the government of British Columbia and close to 50 local governments around the basin, established the Fraser Basin Management Board and Program in 1992. The board's roles include providing advice to all levels of government and others working in the basin, coordinating the development of the strategy for sustainability, and keeping the public informed about the issues and progress towards sustainability. The board also issues periodic "report cards" as well as an annual report on progress towards sustainability in the basin (Fraser Basin Management Program 1994, 1995).

Fraser estuary — waterfowl habitat

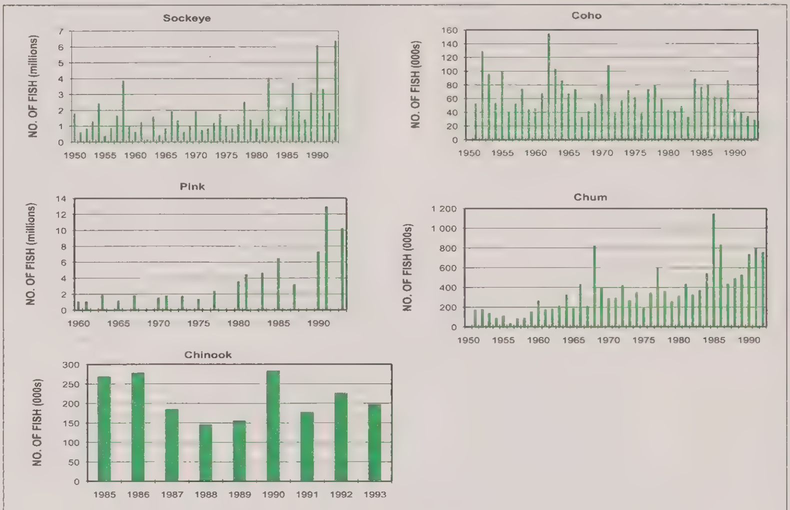
The Fraser River estuary supports the highest density of wintering waterfowl, shorebirds, and birds of prey in Canada. In a typical year, about 1.5 million birds (150 species) use the estuary and its adjacent upland, especially between October and December (Butler and Canning 1989; Butler 1992).

These birds need a variety of habitats, but marshes are particularly important and support about a quarter of the total bird population (Butler and Canning 1989). Up to 70% of the original wetlands and meadows in the lower Fraser River have been altered by human settlement. Much of it was converted to farmland at the turn of the century or used for later urban developments such as Richmond and Delta. However, significant losses are continuing. The total area of wetlands in the southwestern portion of the Fraser lowland declined by 27% between 1967 and 1982 (Pilon and Kerr 1984).

A 1989 inventory classified 25 200 ha of land and water as wetlands in the Fraser estuary (Ward et al. 1992). Of this total, the 4 000 ha of Eelgrass beds (an aquatic plant) and 3 200 ha of marshes are particularly important to the estuary's ecosystem (Ward et al. 1992), and concerted efforts are being made to protect these remaining habitats. A Habitat Compensation Bank, consisting of mudflats that have been converted to marshland, is being used to offset the loss of medium- to low-productivity habitats. Over the last three decades, conservation efforts have

secured large areas of marshland, such as the South Arm Marshes Wildlife Management Area (Butler and Campbell 1987). In addition, the Greenfields project, funded and managed by Environment Canada and delivered by the Delta Farmland Wildlife Trust in conjunction with Ducks Unlimited Canada, encourages farmers in the delta to plant winter cover crops that improve the soil and provide food for wildfowl. Under the Fraser River Action Plan, some 1 200 ha have been planted in the cost-sharing stewardship program. FRAP has also arranged with the Nature Trust of British Columbia to buy land under the Pacific Estuary Conservation Program and has acquired some 40 ha of delta wetlands to date.

Figure 3.27
Fraser River salmon escapements, by species, 1950–1993



Note: Chinook estimates prior to 1984 are not yet available owing to the difficulties in comparing enumeration methods used.
Source: Department of Fisheries and Oceans, Vancouver.

The Fraser River salmon

The Fraser is the world's greatest salmon-producing river. However, compared to a century ago, several of its salmon species are less abundant, in some cases by manyfold. A combination of factors is to blame, including lost habitat, overfishing, and natural causes. Fortunately, the spawning runs (escapements) have much improved since the mid-1980s for several species, including Sockeye, Pink, and Chum salmon.

Coho Salmon, however, have continued to decline since the 1970s, despite many efforts to protect and conserve them. In fact, known populations of Fraser coho are now at or near historic lows of 30 000 spawners (Fig. 3.27). For Chinook Salmon, too, the spawning runs have been relatively low, fluctuating from about 145 000 to 280 000 fish over the past 10 years. Nevertheless, the Fraser remains the largest chinook producer of the Pacific coast.

Chum Salmon are dramatically rebuilding in the Fraser system. Once reduced to only 30 000 spawners in the mid-1950s, the chum now total about 750 000. Another species, the Pink Salmon, has also steadily recovered, from fewer than 2 million in the 1960s to 13 million in 1991.

Of all salmon, the Sockeye Salmon is the most valuable commercially; of all the world's rivers, the Fraser has been the largest sockeye producer. The river's sockeye were decimated in 1913 when a landslide from railroad construction at Hell's Gate prevented spawning fish from returning upriver. Over the years, remedial work on the river and careful fishery management have allowed stocks to rebuild. Since the 1980s, stocks have again approached historical highs of 3–6 million spawners.

Managing salmon is a complex task because there are several species, many populations, numerous harvesters, gradual habitat loss, huge natural shifts, large migrations, and so on. Consequently, changes in their abundance and distribution are difficult to explain.

Some of these problems were dramatically illustrated in 1994 when more than a million sockeye that normally would have migrated to spawning areas could not be accounted for. An independent investigative group, the Fraser River Salmon Public Review Board, set up by the federal government, identified problems with the methods used to estimate stocks, the enforcement of regulations, and management decisions. The board also pointed to aggressive overfishing and warned that the door to disaster would be wide open if the 1994 situation were to repeat itself. The board's recommendations are now being implemented through a five-point action plan, which advocates:

- a more comprehensive approach to managing salmon
- increased enforcement of regulations
- better integration of priorities between fish science and fisheries management
- a tougher stance on the conditions of agreements under the Aboriginal Fisheries Strategy
- more measures to deal with the excessive capacity of the fishing fleets.

Sustainability Within the Ecozones

While the concept of sustainable development is widely recognized, it has proved much more difficult to define in an operational sense. Certainly guidelines to sustainability are offered in the World Conservation Strategy as well as other reports and documents (B.C. Round Table on the Environment and the Economy 1992, 1993a, 1993b, 1993c). Yet the bridge from concept to application remains tenuous. Opinion is divided, sometimes strong-

ly, on what sustainable management practices are. Indeed, views on sustainable management may be diametrically opposed. For example, some people believe that any clear-cutting is an unsustainable practice, whereas others, just as committed to notions of sustainability, believe it is a fully sustainable practice when properly applied. Throughout this debate, public opinion at both the international and local levels plays a strong role.

There is no doubt, however, that considerable progress has been made in several areas with regard to protecting and restoring the ecosystems of these ecozones. For example, major reductions have been made in the organochlorine content of pulp mill effluent, and environmental levels of certain toxic chemicals, such as dioxins and furans, have decreased. Furthermore, some very real progress has been made in extending the proportion of protected area in these ecozones. Some previously closed fisheries have been reopened, and problems of forest sustainability are being tackled more vigorously through mechanisms like Forest Renewal B.C.

There is also no doubt that many problems remain. Population growth and economic development are destroying important wildlife habitats such as wetlands and fragmenting others. Most sewage in the lower Fraser Basin still receives inadequate treatment. Toxic contaminants are present in even the most pristine environments, such as those of the Taiga Cordillera ecozone. In many cases, a lack of adequate ecological monitoring capabilities or sufficient data makes it difficult to detect critical trends or make effective and timely decisions.

Levers of change

In dealing with these problems, society is developing important levers of change — the array of regulations, decision-making processes, partnerships, administrative frameworks, and other mechanisms needed to achieve and manage a sustainable relationship between the economy and the environment.

Recent developments of significance include:

- the Fraser River Action Plan, established in 1991 as a seven-year program to clean up pollution, restore the productivity of the natural environment, and build partnerships to ensure the sustainability of the Fraser River ecosystem.
- the British Columbia *Environmental Assessment Act* of 1995, which provides comprehensive assessment and investigation of the environmental, social, economic, and health implications associated with development proposals.
- the Commission on Resources and Environment, established in 1992 by the Province of British Columbia as an independent commission to help resolve valley-by-valley conflicts over land use.
- the B.C. Protected Areas Strategy, which aims to protect viable, representative examples of terrestrial, marine, and freshwater ecosystems in British Columbia and special natural, cultural heritage, and recreational features.
- the Environmental Cooperation Agreement, signed in 1992 by British Columbia and the state of Washington to coordinate regional-scale efforts to protect, preserve, and enhance the Georgia Basin. The B.C./Washington Marine Science Panel assembled a series of recommendations for halting environmental decline and charting a new course towards improving the condition of shared waters.
- the Georgia Basin Initiative, launched by the B.C. government in 1993, to develop consensus among the provincial, local, and First Nations governments about ways of dealing with growth pressures in the region.
- the Forest Practices Code, announced by the B.C. government in 1994, which provides rules and guidelines related to planning, field operations, forest management administration, and enforcement, as well as specific regulations addressing issues such as clear-cut sizes.
- B.C.'s Forest Renewal Plan, initiated in 1994 to take a portion of the wealth that the forests generate and invest it back into forest regeneration.
- the Yukon Conservation Strategy (1990), which established a policy framework for protection of the environment and sustainable resource use.
- the Yukon *Environment Act* of 1991, which empowers government to take action in a wide range of areas relating to the environment.
- release of the federal "Discussion Paper on Policy Changes to Stumpage Pricing, Reforestation, and Forest Tenure" and the Yukon government's "Framework for Yukon Government Involvement in Forestry" as first steps towards addressing the lack of forest policy in the Yukon and ensuring sustainable use of Yukon forests.

Comanagement with First Nations

As people who have long maintained a special and sustainable relationship with much of this land, the First Nations have a vital role to play in its management. The negotiation of land claims is particularly important in this respect because the agreements will provide the framework in which future uses of these lands will largely be adjudicated and reconciled.

As of 1995, the Yukon land claim settlement became law. The proclamation of settlement legislation was the result of 22 years of negotiations involving the Canadian and Yukon governments and the Council of Yukon Indians. At the same time, final agreements with four of the territory's 14 First Nations were proclaimed.

British Columbia now has one treaty under negotiation. Because of the time needed to negotiate these complex agreements, it is also important to be able to conclude interim agreements on measures that might be affected by government decisions before a final treaty can be concluded. By 1994, three such agreements had been signed between the province and First Nations.

Another important area of comanagement involves traditional fisheries, which have been a cornerstone of the viability of many First Nations communities. By April 1994, under the auspices of the Aboriginal Fisheries Strategy, the Department of Fisheries

and Oceans had signed 150 agreements with 56 First Nations groups within British Columbia (Department of Fisheries and Oceans 1994). These include comprehensive watershed agreements for conserving, monitoring, and regulating fisheries on a river system, communal licence agreements with individual bands and tribal councils, and financial agreements for habitat improvement and stock enhancement projects.

Meeting the challenge

This chapter has shown that some of Canada's rarest, most diverse, and most productive ecosystems are seriously threatened by human activities. These threats extend even to remote areas such as the Taiga Cordillera. With further population growth and economic development, these pressures will become even greater, particularly in the southern portions of the Pacific Maritime and Montane Cordillera ecozones. Achieving sustainability even at present levels of population and economic activity is a difficult enough task. Doing so in the future will be a far more formidable challenge.

Meeting this challenge will require a further transformation of our attitudes towards the environment and our lifestyles, as well as additional changes in technology, urban planning, administrative frameworks, and ways of doing business. What has been accomplished so far has been valuable, but if sustainability is to be attained and preserved in the future, we must build even more ambitiously on these foundations.

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For Further Reading

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Chapter 4 Central Plains Ecozones

Highlights

The Central Plains region, which covers 114.9 million hectares, or 12% of Canada, encompasses much of the land area of the Prairie provinces. It includes the central and western portions of southern Manitoba, the lower half of Saskatchewan, and most of Alberta, and it edges into the Northwest Territories and the Peace River region of British Columbia.

■

The Central Plains region consists of two terrestrial ecozones. Agriculture dominates the Prairies ecozone, with 97% of the land mass classified as agricultural, whereas forestry is pervasive in the more northern Boreal Plains ecozone, where forests cover 84% of the land.

■

Agriculture has diversified considerably in recent years in the Prairies ecozone, from the traditional grain crops to more oilseed crops, such as canola, flax, and sunflowers. Producers have increasingly adopted more sustainable farming practices, including conservation tillage and reduced summerfallow, reducing the risk of water and wind erosion.

■

In the Boreal Plains ecozone, the rate of forest harvesting — especially of the previously little-used aspen stands — has increased greatly in recent years. Between 1990 and 1992, the federal government signed new agreements with the three Prairie provinces to maintain and enhance the long-term health of the forests.

■

Dams and reservoirs have been constructed on all the major river systems in the Prairies ecozone, with two completed in Saskatchewan and one in Alberta in the past five years. The most significant cause of water degradation in the ecozone is urban sewage and runoff from fertilized agricultural lands.

■

Pulp mills have become one of the biggest users of water resources in the Boreal Plains ecozone and a significant source of effluent. Governments and industry have developed new pulp mill technologies, and all mills are complying with federal regulations introduced in 1992 to curb effluent emissions.

■

The variety of wildlife species in both ecozones has been greatly reduced. Thirty-seven species of birds, mammals, and plants that inhabit the Prairies ecozone have been placed on the List of Species at Risk in Canada.

■

Temperature increases in the Prairies ecozone have exceeded the overall global rise, particularly in the past 15 years. Climate forecasts predict a 5–7°C rise in annual surface temperature for the Prairie provinces over the next 50 years, causing greater and longer shortages in water supplies.

■

Resource management in the Central Plains region has become increasingly characterized by a holistic, ecosystem approach, one that recognizes the interdependencies of all elements in an ecosystem. Each of the Prairie provinces has adopted sustainable development strategies.

■

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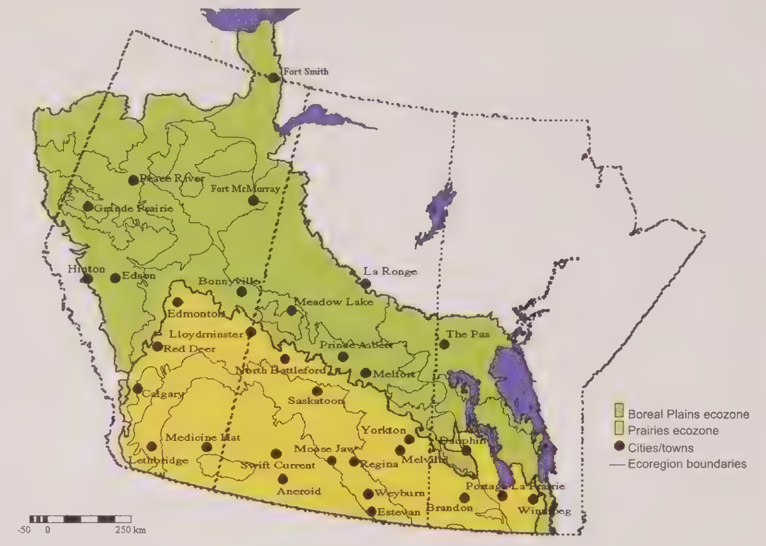
Introduction: The Setting

The Central Plains region encompasses much of the land area of the Prairie provinces. It covers the central and western portions of southern Manitoba, the lower half of Saskatchewan, and most of Alberta, and it edges into the Northwest Territories and the Peace River region of British Columbia. The total area is 114.9 million hectares, or 12% of Canada. The Central Plains region is divided into the Prairies ecozone to the south, composed mostly of agricultural cropland and grasslands, and the agricultural and forested Boreal Plains ecozone to the north (Fig. 4.1a). The two ecozones converge in a unique territory called the transition zone, an area consisting mostly of aspen parkland, where the southern prairie gradually gives way to tree cover. This chapter provides an overview of economic and social developments in these two ecozones and the central environmental issues they face.

Over the past 100 years, both ecozones have undergone development by natural resource industries, largely agriculture and forestry, but also oil and gas extraction and refining, hydroelectric power generation, fisheries, and mining. Although these industries have fostered a thriving economy and high standard of living, they have also greatly modified the original ecosystems, diminishing wildlife and plant populations. Farming operations alone now occupy 49% of the area (Morrison and Kraft 1994).

As the following sections discuss, however, the Central Plains are also embracing the worldwide trend towards sustainable development. Rooted in the 1987 report of the World Commission on Environment and Development (the Brundtland Commission), entitled *Our common future*, this philosophy is bringing about a fundamental shift from treating the environment primarily as a natural resource to treating it as an integrated ecological whole. Governments, industry, and the public are recognizing that sustaining the resource economy means safeguarding environmental considerations in concert with social and economic values, both now and into the future.

Figure 4.1a
Cities/towns in the Prairies and Boreal Plains ecozones



Source: State of the Environment Directorate, Environment Canada.

Snapshot of the Prairies ecozone

The Prairies ecozone consists of a flat to gently rolling landscape underlain by deep glacial deposits. This largely level topography makes the area ideal for mechanized farming (Acton and Gregorich 1995). Prior to European settlement, the ecozone consisted largely of dry mixed grasslands in southeastern Alberta and southwestern Saskatchewan, aspen parkland and fescue prairie through the transition to the Boreal Plains ecozone in the north, and tallgrass prairie in the southeastern prairies of Manitoba. The grasslands were grazed by many wild mammals, primarily bison, but also North American Elk, deer, and Pronghorn.

Since European settlement, the ecozone has become one of the most extensive agricultural regions in the world. Its total land area is about 47 million hectares. Of that, 70% is classified as cropland and 27% as rangeland and pasture. The remaining 3% is deciduous forest (Fig. 4.1f). Domesticated species of economic significance in the ecozone now include beef and dairy cattle, swine, horses, chickens, and turkeys (Morrison and Kraft 1994).

The high natural fertility and good moisture-holding capacity of many of the soils of the Prairies ecozone make the area extremely productive for crops (Acton and Gregorich 1995). The ecozone is dominated by four chernozemic soil types: brown, dark brown, black, and dark grey. The brown and much of the dark brown soil zones contain drier and lighter soils, which makes them less suitable for annual crop production and therefore more commonly allocated for cattle grazing. Yet these zones still include about 30% of the land capable of grain production in the ecozone.

Most of the major rivers originate in the Rocky Mountains, which constitute the western boundary of the Prairies and Boreal Plains ecozones. These rivers, fed mostly by snowmelt, glacial runoff, and rainfall, flow in an easterly direction across the Prairies. All of the major rivers are regulated and used for power generation, water supply, and recreation. Depending on the weather conditions, the ecozone can contain between 2 and 7 million wetlands. The greatest number of

Figure 4.1b

Air temperature, degree-days, and precipitation in selected centres

Selected centres	Air temperature (°C)				Degree-days[a]		Precipitation			
	Mean January maximum	Mean January minimum	Mean July maximum	Mean July minimum	Heating (<18°C)	Growing (>5°C)	Mean annual rainfall (mm)	Mean annual snowfall (cm)	Mean total precipitation (mm)	Days with measurable precipitation
Fort Smith, N.W.T.	–20.3	–30.5	22.7	9.8	7 692	1 162	231	154	353	128
Calgary, Alta.	–3.6	–15.7	23.2	9.5	5 195	1 435	300	135	399	111
Edmonton, Alta.	–8.7	–19.8	22.5	9.4	5 828	1 352	358	127	466	122
Edson, Alta.	–5.3	–18.5	21.7	7.7	5 895	1 122	443	180	568	136
Fort McMurray, Alta.	–14.5	–25.3	23.2	10.0	6 529	1 352	335	172	465	142
Aneroid, Sask.	–7.1	–18.7	27.6	10.6	5 227	1 759	244	103	347	82
La Ronge, Sask.	–15.4	–26.5	22.8	11.0	6 789	1 300	355	155	489	139
Prince Albert, Sask.	–13.7	–26.1	24.2	10.9	6 437	1 455	302	117	406	121
Regina, Sask.	–11.0	–22.1	26.3	11.9	5 756	1 723	281	107	364	109
Saskatoon, Sask.	–12.3	–22.9	25.4	11.7	5 944	1 658	254	105	347	108
The Pas, Man.	–16.4	–26.5	23.4	12.1	6 736	1 395	323	170	452	127
Winnipeg, Man.	–13.2	–23.6	26.1	13.4	5 874	1 802	404	115	504	119

Note: Data based on 1961–1990 climatic normals.

[a] A unit of measurement of the deviation of the mean daily air temperature from a predetermined standard (at a particular location). For further details, see definition of degree-days in Glossary.

Source: Environment Canada (1994).

Table 4.1

Rural/urban population change in the Prairies ecozone, 1971–1991

	1971		1981		1991				
	No. of persons	% of total	No. of persons	% of total	No. of persons	% of total	% change, 1971–1981	% change, 1981–1991	% change, 1971–1991
Rural	770 147	26.4	776 057	22.2	731 057	19.0	0.9	–5.9	5.1
Urban	2 147 180	73.6	2 724 363	77.8	3 120 032	81.0	26.9	14.5	45.3
Total	2 917 327	100.0	3 501 068	100.0	3 500 420	100.0	20.0	10.0	32.0

Source: State of the Environment Directorate, Environment Canada.

wetlands occurs along the subhumid northern grasslands and adjacent aspen parkland, where 25–50% of the land surface is wetlands (Morrison and Kraft 1994). Many former wetland areas have been converted to agricultural production.

The Prairies ecozone is significantly colder during the winter than most other major grain-growing areas in the world. Summer temperatures are somewhat cooler, annual precipitation is considerably less, and the frost-free period of 103–129 days is considerably shorter. Annual precipitation ranges from about 500 mm in eastern and northern regions to about 300 mm in the southwest (Fig. 4.1b).

The economic structure of the ecozone has continued to undergo a shift that began in the 1950s, with urban growth and rural depopulation becoming dominant trends. The majority of population increases in the major urban centres are due to a migration of people from rural areas, as well as the influx of new residents seeking job opportunities. Technological change in agriculture, increased labour productivity, and reduced labour requirements, as well as improvements in transportation, have led to a decline in the need for numerous, dispersed rural centres to support the needs of the agricultural sector. In 1991, 81% of the total population of 3.85 million resided in urban areas (Figs. 4.1c and 4.1d; Table 4.1).

Over the past two decades, the tertiary (service) sector has come to constitute about 80% of the ecozone's labour force, growing much more quickly than the traditionally dominant primary and secondary (manufacturing) industries. Tertiary industries blend both the traditional consumer services with high-technology and knowledge-intensive (business

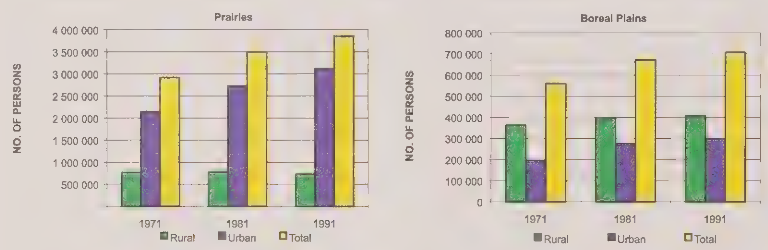
Figure 4.1c
Population change in selected centres, 1971–1991

Selected centres	Population 1971	1991	% change
Fort Smith, N.W.T.	2 364	2 480	5
Calgary, Alta.	403 319	754 033	87
Edmonton, Alta.	495 702	839 924	69
Edson, Alta.	3 818	7 323	92
Fort McMurray, Alta.	6 847	34 706	407
La Ronge, Sask.	905	2 578	185
Prince Albert, Sask.	28 464	34 181	20
Regina, Sask.	140 734	191 692	36
Saskatoon, Sask.	126 449	210 023	66
The Pas, Man.	6 065	6 166	2
Winnipeg, Man.	540 262	652 354	21

Note: The geographic extent of a Census Metropolitan Area in 1971 may not correspond to that for 1991. For further details, see Endnotes.

Source: Special tabulations prepared by Statistics Canada. For further details, see Endnotes.

Figure 4.1d
Population trends, 1971–1991



Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada. For further details, see Endnotes.

and insurance) industries, which provide services to national and international clients (Table 4.2).

This ecozone has a higher proportion of its labour force in secondary industries than the national average, reflecting the importance of its major urban centres of Edmonton, Calgary, Saskatoon, Regina, and Winnipeg in serving national and international markets. It also reflects the value-added opportunities related to the region's resource base through agricultural processing, petroleum products, and complementary industries such as agricultural implements, pipeline products, and petroleum industry hardware.

Snapshot of the Boreal Plains ecozone

The Boreal Plains ecozone belongs to the vast boreal forest ecosystem that extends across North America and around the world at high northern latitudes. The ecozone occupies a land area of about 67.9 million hectares, making it slightly larger than the Prairies ecozone (Fig. 4.1a). About 84% of the land surface is covered by coniferous, mixedwood, or deciduous forests, including such species as spruce, pine, and aspen. Agricultural cropland and rangeland occupy the other 16%, mainly in that part of the ecozone situated in the transition zone (Fig. 4.1f). Most of the ecozone is underlain by flat-bedded sedimentary bedrock, although it extends into the rugged foothills of the Rocky Mountains. The landscape is gently rolling or level over most areas.

Fire is a natural regenerating tool that exerts a major influence on the ecozone's forests, regulating their distribution and growth. The 10-year annual average of areas burned for the three Prairie provinces is some 1.2 million hectares (Higgins and Ramsey 1992). In some years, fire engulfs unusually large areas, despite improved fire suppression and prevention methods. In 1989, over 0.6 million hectares burned in the Manitoba portion of the Boreal Plains ecozone alone. Another particularly bad year was 1995, when fire consumed nearly 1.6 million hectares in Saskatchewan's Boreal Plains and Boreal Shield ecozones.

The ecozone's characteristic soils are the dark grey and grey luvisols, which formed under the mixed deciduous and coniferous forests (Morrison and Kraft 1994). In poorly drained areas, extensive peat bogs have developed. Peatlands form an essential part of the wildlife habitat of the ecozone, often remaining after major fires to provide food and shelter for many wildlife species. Bogs, with their ground and tree lichens, are the main habitat for Woodland Caribou. Beavers alter the water storage regime of the forests by building dams on creeks. Common predatory species include Wolves, Coyotes, and Red Foxes.

About 7% of the ecozone is covered by fresh water, with Lake Winnipeg and Lake Winnipegosis being the largest lake basins. Most of the large river systems flowing through the ecozone (Peace, Athabasca, North Saskatchewan) originate in the Rocky Mountains. The only exception is the Red River, which flows north from the United States and, after being joined by the Assiniboine River, flows into Lake Winnipeg. Lake Winnipeg is the source of the Nelson River, which flows into Hudson Bay.

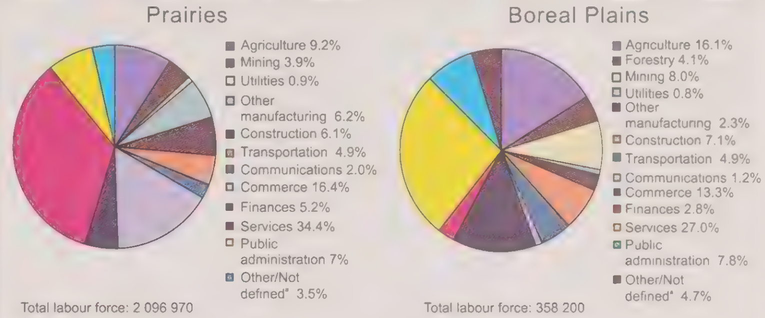
The climate is harsh in the winter, with a mean January temperature of –20°C, and pleasant in summer, with a mean July temperature of 20°C (Fig. 4.1b). The

annual precipitation, about 450 mm, is greater than the potential rate of evaporation, resulting in surplus moisture of up to 10 cm near the southern edge and surpluses of up to 30 cm in the north and in the foothills (Hogg 1994).

The population of the ecozone experienced a 5.4% increase between 1981 and 1991, but it still remains sparse, at about 708 000 people. Whereas about 58% of the population lives in rural areas, both rural and urban populations have been increasing gradually over the past two decades, with the urban growth exceeding that of rural areas (Table 4.3).

The ecozone's economy is based on expanding resource industries, primarily forestry and agriculture, but also mineral and oil extraction and processing. The ecozone contains large inventories of petroleum and mineral deposits. Since the 1980s, harvesting of the previously underutilized aspen trees, for use in the pulp industry, has greatly expanded. Despite an overall dependence on resource production, the ecozone's economy has experienced a shift towards the tertiary sector. The labour force in the primary sector grew by 6%, whereas the secondary sector (manufacturing) declined by almost 4% between 1981 and 1991. Both sectors' overall share of the labour force declined. The tertiary industry increased its share of the total labour force from 77.3% to nearly 80%. Primary industries employed about 12% and secondary industries 8% of the labour force (Bjonback 1995).

Figure 4.1e
Labour force composition, 1991



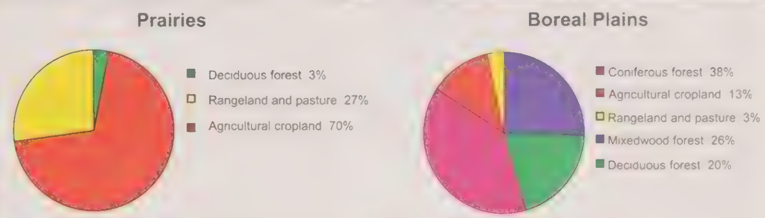
Note: Using the 1970 Standard Industrial Classification, the four primary sectors have been grouped with their respective first-stage resource processing industries. For further details, see Endnotes.

* "Other/Not defined" represents labour force categories that were less than 0.5% of the total labour force as well as responses for which the respondent did not specify the industrial category in which he/she or other household members were employed.

° Numbers in each sector have been rounded to the nearest five.

Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada

Figure 4.1f
Land cover distribution



Note: For the definitions of surface cover types, see legend to Figure 10.11, Chapter 10

Source: National Oceanic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR) imagery; Manitoba Remote Sensing Centre, Manitoba Department of Natural Resources

Snapshot of the transition zone

The division between the Prairies and Boreal Plains ecozones occurs over a geographically diverse area called the transition zone (Fig. 4.2), where prairie grasslands give way gradually to a more forested terrain. Thousands of shallow ponds, or sloughs, dot the landscape in the southern portion of the zone. These are surrounded by marshy shallows that provide superior habitat for many species. The large number of shallow water bodies makes the zone extremely important habitat for waterfowl and shorebirds, and the diversity of bird species in the area is among the highest in North America. The zone is also home to a number of large mammal species, including White-tailed Deer, Moose, Black Bear, Coyote, Wolf, Red Fox, Caribou, beaver, and North American Elk. Three of the main cities of the Central Plains, Edmonton, Calgary, and Winnipeg, are located in the zone.

In the southern part of the zone, the natural vegetation is aspen parkland or grasslands and aspen bluffs and, in western Manitoba and eastern Saskatchewan, Bur Oak. Only portions of this prairie and forest mosaic remain, as much of the landscape has been cultivated for agriculture or harvested for the forest industry. The proportion of forested areas increases northward and the grasslands decrease, forming a gradual transition through the Boreal Plains ecozone to the boreal forest. The natural vegetation becomes closed-canopy broadleaf forest, generally with a scattering of conifer trees.

The zone has three main soil types that vary in extent of fertility. The dominant soil in the aspen parkland is the highly fertile black chernozemic soil (Clayton et al. 1977). It contains a high level of organic matter; the soil limitations to growing field

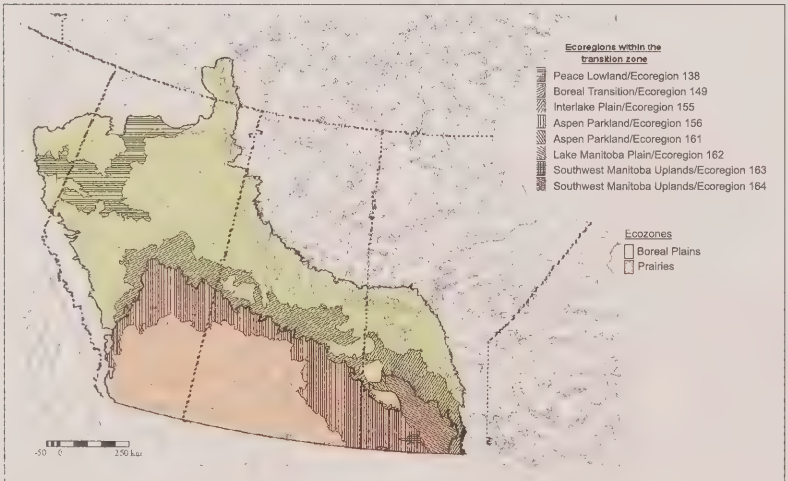
Table 4.2
Prairies ecozone labour force, by sector

	1981		1986		1991		
	No. of persons	% of total	No. of persons	% of total	No. of persons	% of total	% growth, 1981–1991
Primary							
Agriculture	155 965	8.8	167 685	8.8	168 715	8.3	8.17
Fishing and hunting	440	0.0	375	0.0	460	0.0	4.55
Forestry	1 280	0.1	1 525	0.1	2 960	0.2	131.25
Mining	65 860	3.7	69 010	3.6	65 375	3.2	–0.74
Subtotal	223 545	12.6	238 595	12.5	237 510	11.7	6.25
Secondary							
Manufacturing	180 635	10.1	171 910	9.1	172 525	8.5	–4.49
Subtotal	180 635	10.1	171 910	9.1	172 525	8.5	–4.49
Tertiary							
Wholesale and retail trade	314 120	17.6	326 500	17.2	342 765	16.9	9.12
Communication	40 515	2.3	39 190	2.1	42 665	2.1	5.31
Construction	155 470	8.7	121 840	6.4	127 050	6.3	–18.28
Finance	98 815	5.5	100 655	5.3	109 290	5.4	10.60
Public administration	136 840	7.7	148 790	7.8	153 345	7.6	12.06
Public utilities	19 670	1.1	21 255	1.1	22 310	1.1	13.42
Services	512 985	28.8	628 445	33.1	720 265	35.5	40.41
Transportation and storage	100 100	5.6	101 620	5.4	102 850	5.1	2.75
Subtotal	1 378 515	77.3	1 488 295	78.4	1 620 540	79.8	17.56
Total labour force	1 782 695	100.0	1 898 800	100.0	2 030 575	100.0	13.90

Note: Percentages may not add up owing to rounding.

Source: State of the Environment Directorate, Environment Canada.

Figure 4.2
The transition zone



Source: State of the Environment Directorate, Environment Canada.

crops in the zone vary from insignificant to moderately severe (Energy, Mines and Resources Canada 1985). The soils farther north, in the southern fringe of the Boreal Plains ecozone, are the less fertile grey luvisols. Most of the organic materials and clay particles in these soils have been removed, rendering them somewhat acidic (Clayton et al. 1977). In other parts of the zone, the soils are dark grey luvisols. These have a higher organic matter content and are therefore more productive than other grey luvisols. Climatic hazards, such as short growing seasons and unseasonable frost, may limit the success of field crops in some years, but droughts are less frequent than in the Prairies ecozone.

Stages of human influence affecting the Central Plains

Prior to entering the current era of more sustainable development, the Prairies and Boreal Plains ecozones passed through three earlier stages of development: the

Table 4.3
Rural/urban population change in the Boreal Plains ecozone, 1971–1991

	1971		1981		1991				
	No. of persons	% of total	No. of persons	% of total	No. of persons	% of total	% change, 1971–1981	% change, 1981–1991	% change, 1971–1991
Rural	362 908	64.8	395 388	58.9	408 676	57.7	8.9	3.4	12.6
Urban	196 783	35.2	276 289	41.1	299 019	42.3	40.4	8.2	52.0
Total	559 691	100.0	671 677	100.0	707 695	100.0	20.0	5.4	26.4

Source: State of the Environment Directorate, Environment Canada.

exploratory, pioneer period of hunting, trade, and settlement; the development of resource industries, such as agriculture, forestry, and nonrenewable resource exploration and development; and a managed state that recognized the multiple-use capabilities of the land base.

The first stage generally dates back to the activities of the Hudson's Bay Company, which in 1670 was given a monopoly on fur trading in a huge area then known as Rupert's Land. Prior to this European arrival, the most significant impacts on the landscape had come from grass fires, forest fires, and the grazing and trampling impacts of bison. Some suggest that pre-European Aboriginal hunting decimated populations of large mammals (Kay 1996). However, the intensity of pre-European hunting remains controversial among anthropologists. By the 1780s, a burgeoning European demand for bison fur prompted a period of widespread bison hunting, leading to the virtual elimination of free-roaming herds.

The resource extraction stage was rooted primarily in a national government initiative to develop agriculture, as a means of securing the Central Plains from potential encroachment by the United States (Morrison and Kraft 1994). During the early 1800s, the Hudson's Bay Company and the North West Company failed in attempts to nurture limited agricultural development. In 1870, with fur supplies dwindling and bison meat becoming less available to sustain hunting outposts, profits were declining, and the Hudson's Bay Company sold most of its land, timber, and mineral rights to the new Government of Canada. The government completed the transcontinental railway in 1885 and offered Europeans land to homestead in quarter sections (65 ha). A major influx of settlers and significant cultivation of the prairies began around 1900 (Fig. 4.3).

Such government initiatives as the Crow's Nest Pass Agreement of 1897 provided rail shipments of grain at reduced prices and therefore encouraged grain production over other land uses. The Canadian Pacific Railway also created markets for beef, launching the use of rangelands in the Prairie provinces for cattle ranching.

The spread of settlement across the Prairie provinces spurred demands for lumber. In the Boreal Plains ecozone, large sawmills were in operation by 1900, and over the next 70 years pulp mills grew up across the ecozone, using mainly conifer species. In the Alberta portion of the ecozone, the arrival of the railroad also launched a coal mining industry. Oil was discovered in the 1920s, and exploration soon spread, with oil and gas production increasing greatly in the post-World War II years. To explore, produce, and deliver these products to markets, a vast road, railroad, and pipeline network was developed, and thousands of kilometres of lines were cut for seismic exploration.

As forestry became more mechanized in the mid-1950s, the pace of harvesting increased. Exploration for hydrocarbon resources and their development took place in the western part of the Boreal Plains ecozone, mainly after 1945. At this time, Manitoba and Saskatchewan began developing hydroelectric power plants, which altered the natural landscape through dam construction and flooding for reservoirs.

Many land users, particularly farmers, always sought to make their activities sustainable. However, it was not until the 1960s that a trend began towards more systematic management of the land base across Canada. Multiple land uses and priorities began to be considered and evaluated. The 1961 Resources for Tomorrow Conference, a meeting of federal and provincial ministers responsible for natural resource sectors, became the cornerstone of a movement towards assessing land and environment with a view to sustaining a range of land capabilities. In forestry, for example, the conference launched an evaluation of forest conservation policies and the development of activities that went beyond resource maintenance and harvesting regulations to include proactive reservation for other uses. Land assessment included species and habitat preservation, recreation, agriculture, and forestry (Bjonback 1995).

The Canada Land Inventory Program, a joint federal–provincial initiative, also grew out of the Resources for Tomorrow Conference. The inventory recognized and identified the diverse and overlapping capabilities of various land areas. The 1970s marked a period of analyzing these data to determine how land use regulations should be applied to maximize the benefits of specific areas. The assessment of lands according to their capability formed the basis of Canada's efforts in sustainable land use, a concept that was gaining momentum worldwide and that would culminate in the 1987 Brundtland Commission report, *Our common future*.

In the 1990s, the concept of sustainable development has become paramount. The remainder of this chapter explains the meaning of this new approach and illustrates how it is being implemented by governments, industry, and landowners throughout the Central Plains.

Environmental Issues by Ecozone

Achieving long-term sustainability has become a central objective in the Prairies and Boreal Plains ecozones. It means making a conceptual shift from sustaining the production of goods and services to sustaining the viability of environmental, social, and economic systems (Kaufmann et al. 1994). This shift is being driven by a growing recognition that the degradation of soils, water, atmosphere, and forests affects economic prospects (World Commission on Environment and Development 1987).

Adopting this sustainable approach requires recognizing the interdependencies of elements within the various ecosystems. An ecosystem is identified as a fairly distinctive geographical setting, with its own particular complement of plants, animals (including humans), and other organisms, together with air, water, soils, and rocks (see Chapter 1). Ecosystem management stipulates the need to evaluate all socioeconomic activities and environmental factors in unison, so that economic opportunities provide benefits without jeopardizing biodiversity and ecosystem integrity (Alberta Environmental Protection 1995). The following sections discuss selected activities that have environmental impacts in these two ecozones and outline measures being taken to encourage more sustainable practices.

Figure 4.3
Encouraging settlement in the 1900s

Source: McKee and Klassen (1983).

Prairies ecozone

The Prairies ecozone is affected by both naturally occurring and human-induced stresses, resulting in a variety of environmental issues. These include the loss of habitat and wildlife, urban sprawl, climate change and variability, streamflow regulation, floods and droughts, and degradation of land, air, and water quality. More recent issues that have emerged include the inadvertent introduction of foreign species and impacts on riparian systems or riverside vegetation.

This section focuses on recent trends in three significant areas: agriculture, which accounts for many of the major environmental impacts; water quality and quantity; and effects of landscape alteration on wildlife populations and habitat. Climate change and variability, issues gaining regional, national, and global significance, are addressed in a later section.

Agriculture in transition

In the past decade, agricultural practices in the Prairies ecozone have undergone significant changes. Many experts believe that agriculture in the ecozone is becoming more environmentally sustainable, because of global changes in agricultural policies and more sustainable farming practices (Wilson and Tyrchniewicz 1995). Worldwide, fiscal constraints and a greater reliance on market forces have led nations to reduce agricultural subsidies and tariff protection. In Canada, this trend resulted in the 1995 elimination of the approximately $650-million annual grain transportation subsidy, a policy under the *Western Grain Transportation Act*. Elimination of subsidies is a principle of the

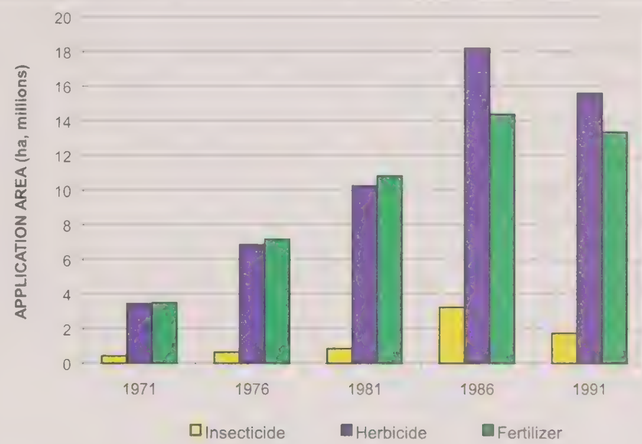
General Agreement on Tariffs and Trade, which Canada has signed.

The *Western Grain Transportation Act* provided producers of export-bound grains and oilseeds with a subsidy of about one-third to one-half of the railway transportation costs. Owing in part to the forerunner of this policy, the Crow's Nest Pass Agreement, about 14 field crops (grain, oilseeds, and pulses) became the mainstay of agriculture in the ecozone. These crops and a variety of forage crops occupy over 95% of the cropped area of western Canada (Morrison and Kraft 1994). A trend towards devoting large areas to a single crop or an intense crop rotation production system, with larger, more mechanized farms, has been followed since the 1950s. Some experts predict that the subsidy's elimination will lead farmers in the Prairies ecozone to diversify, planting a greater variety of crops and raising more livestock. They anticipate that value-added activities, whereby products are processed in Canada before being exported, will also increase (Wilson and Tyrchniewicz 1995).

International market forces have already had a significant impact, changing cropping practices and diversifying the landscape. The low returns that traditional grain crops (e.g., wheat, barley, rye, and oats) provided from the early 1980s until prices rose in 1995 led producers to grow more oilseed crops (e.g., canola, flax, and sunflowers). The area devoted to canola alone has increased by 700% since 1976. From 1976 to 1991, the area devoted to field peas increased from 20 000 ha to 150 000 ha, whereas the area of lentil production increased from less than 1 000 ha to more than 300 000 ha. Other crops of increasing significance include potatoes, canary seed, field beans, and mustard (Statistics Canada 1992).

Whether this increased diversity will benefit the environment is unclear. To ensure high economic returns, oilseeds and other field crops require more chemical inputs than do traditional grain crops. Higher application rates for fertilizers and pesticides often increase their environmental risks. The application of preemergent

Figure 4.4
Agricultural inputs in the Prairies ecozone, 1971–1991



Note: Estimates for 1976.
Source: Statistics Canada (1992), reworked by the Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

chemicals for weed control in oilseed production and the associated tillage increase the risk of soil erosion over control methods used for grain crops. However, new oilseed varieties are being tested that will permit the use of postemergent chemicals and reduce tillage requirements. The outstanding risk of oilseed over grain crops is that there are lesser amounts of stubble to protect the soil.

The area of land treated with fertilizer, herbicides, and insecticides has gradually increased since the early 1970s, as a mounting number of products become available to deal with specific pest problems (Fig. 4.4). Sales of these chemicals have slowed somewhat since the mid-1980s owing to the combination of reduced need and falling commodity prices. The impact of these chemicals on water quality has become a significant environmental concern, an issue addressed in detail in the next section. However, industries are making significant efforts to ensure that products are environmentally sustainable. Many new pesticides are less persistent and are applied in ways that lower the risk associated with their use on large areas.

Producers are increasingly adopting more sustainable farming practices, such as conservation tillage and reductions in summerfallow, to gain both economic and environmental benefits. Conservation tillage means tilling less and leaving more of the previous year's crop residue on the field surface. For much of the past century, Canadian farmers have cultivated the land by returning the residue left from the harvest crop to the soil. This process contributes to soil degradation by removing the protective vegetation cover provided by the plant material and by altering the soil structure. Leaving residue on the surface protects the soil from wind and water erosion, conserves soil moisture, provides a protective canopy for the growing crop, maintains soil organic matter, and enhances nesting cover for wildlife, particularly when fall seeded crops are planted. Although conservation tillage reduces overall farm input costs because of lower energy requirements, application of herbicides is needed to control the weed growth that tillage would otherwise eliminate.

Since the early 1900s, Prairie farmers have also commonly practised summerfallowing — leaving a parcel of land free of

Table 4.4
Changes in the amount of summerfallow in the Prairie provinces, 1941–1991

Province	Area (ha, 000s)					% change, 1961–1991
	1941	1961	1971	1986	1991	
Manitoba	1 118	1 307	1 074	509	297	-77
Saskatchewan	5 586	6 952	6 701	5 658	5 713	-18
Alberta	2 649	3 015	2 836	2 126	1 771	-41
Prairies total	9 353	11 274	10 611	8 293	7 781	-31

Source: Statistics Canada (1992), reworked by the Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

Table 4.5
Area converted to forage through the Permanent Cover Program (PCP) I and II, 1989–1994

Program	Area (ha)				
	British Columbia	Alberta	Saskatchewan	Manitoba	Total
PCP I	0	83 782	63 813	20 892	168 487
PCP II	4 836	137 090	145 419	66 559	353 904
Total	4 836	220 872	209 232	87 451	522 391

Source: Prairie Farm Rehabilitation Administration (1995).

crops for a single growing season (Table 4.4). The land is cultivated only to control weeds and is left idle to store extra moisture and to release nitrogen from the soil's organic matter to help produce the following year's crop. A drawback of summerfallowing is that leaving the land cropless exposes the soil to erosion by wind and water. It may also increase infiltration to groundwater, which may lead to salinization at discharge locations and may intensify water evaporation, which may also increase soil salinization.

In the fall of 1993, a crop residue survey of more than 5 000 individual fields was conducted (B. Fairley, Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada, personal communication) throughout Saskatchewan and Alberta to assess crop type, condition of stubble (short vegetative stalks of plants left after harvesting), and the amount of crop residue. Over 3 000 of these same fields had been surveyed in the fall of 1988. Summerfallow had decreased from 22% to 17% of fields surveyed. In Saskatchewan, the trends were slightly different, with a slight increase in cereal crop acreage and small increases in oilseeds, pulses, and forages. Summerfallow had declined from 41% to 32% of fields surveyed. Overall, summerfallow acreage in the ecozone has decreased in recent years by about 8.3% annually.

These surveys also showed that, by 1993, 13% of the Alberta sites had been planted to forage or food for livestock, reflecting the province's trend towards increasing cattle production. Production of cereal crops had decreased somewhat, whereas slight increases had occurred in oilseed and pulse crops.

In both Alberta and Saskatchewan, the trend is towards more standing stubble on cropped fields and more partially standing stubble on summerfallow fields. In both provinces, the researchers observed an increase in the amount of residue remaining on cropped fields. In 1988, about 70% of cereal fields had more than 1 000 pounds of residue per acre (1 121 kg/ha); in 1993, cereal fields with more than 1 000 pounds per acre represented 85% of the surveyed fields in Alberta and 98% of those in Saskatchewan.

Farmers are learning the benefits of conservation tillage through research. In 1993, Manitoba producers joined with Ducks Unlimited Canada and the Government of Canada's Parkland Agriculture Research Initiative to form the Manitoba Zero Tillage Research Association. A 260-ha parcel of land was established near Brandon, dedicated to soil conservation and habitat preservation. As farmers run this centre, they see the costs of its programs and can judge whether these are financially feasible for their own farms. As well, Manitoba's Keystone Agricultural Producers organization has devised a checklist that farmers can use in determining whether a proposed project is both economically and environmentally viable. Similar ventures are under way in Alberta and Saskatchewan.

Between 1989 and 1994, farmers took over 500 000 ha of farmland out of annual crop production under the Permanent Cover Program, an initiative undertaken in the three Prairie provinces and the Peace River region of British Columbia by the Prairie Farm Rehabilitation Administration of Agriculture and Agri-Food Canada (Table 4.5). The program's main objective was to reduce soil degradation by removing marginal land (land least suited to annual crops) from production and returning it to a state of permanent cover. The program placed no restrictions on the use the farmer makes of the land. Most participants used these lands for producing hay for livestock, and about two-thirds also used the land for grazing.

Recent research indicates that conservation practices have moderated deterioration in the health of agricultural soils. In 1989, Agriculture Canada set up 23 study sites across Canada to provide a capability to study various soil quality parameters at those sites on an ongoing basis. Erosion risk calculations were done for 1981 and 1991. The initial measurements, released in 1995, are reported not by ecozone but by province. The results of this research, combined with other models, indicate that the risk of water erosion has been reduced

by 13% in Alberta, 8% in Saskatchewan, and 15% in Manitoba. Only about 5% of cultivated land is at risk of water erosion losses exceeding tolerable limits. Risk of wind erosion has decreased by 7% overall. The percentage of land at high to severe inherent risk of wind erosion is 31% in Alberta, 40% in Saskatchewan, and 35% in Manitoba. The research found that uneroded soils had lost 15–30% of organic matter since first being cultivated, in part as a result of summerfallowing. Under 1991 cropping practices (as indicated by the 1991 Census of Agriculture), there was little or no risk of a change in salinity levels in about 61% of agricultural lands in Manitoba, 59% in Saskatchewan, and 80% in Alberta. The remaining farmland in these provinces had a moderate to high risk of increasing salinity under 1991 cropping patterns (Eilers et al. 1995).

The Prairies ecozone has also been experiencing a trend towards increased livestock production. The ecozone's large land base and low livestock population densities create a potential for this growth. For the Prairie provinces as a whole, cattle production declined from 9.5 to 7 million head between 1975 and 1986, then increased to nearly 9 million head in 1993. Hog production has gradually risen from 2 million in 1976 to just over 4 million in 1993 (E.G. O'Brien, Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada, personal communication). Some experts expect that a growing demand from Asian countries will further stimulate livestock expansion. Researchers forecast a two- to threefold increase in hog production in western Canada by the year 2000.

The trend in livestock production is from small farm operations towards larger, more efficient agricultural production units, called intensive livestock operations. One of the main environmental challenges facing these intensive livestock operations is the management of livestock manure. Manure is a source of air, water, and land pollution because it emits greenhouse gases and contains nitrates, salts, and heavy metals. Livestock manure — whether from hogs, poultry, or cattle — can be a source of bacteria, viruses, and parasites. Concentrated operations create unpleasant odours, a significant problem as residential developments expand into agricultural areas. Conversely, manure is also a potentially important source of the nutrients required for crop production. However, it must be stored, handled, and applied in a manner that minimizes its potentially negative impacts on air, water, and soil quality. Each of the western provinces has designed codes or guidelines providing for the safe and economic handling of animal manures.

In the future, with growing populations and income, world demand for Prairie food products is expected to increase. Currently, about 75% of production of the Prairies is exported. In order to remain internationally competitive and meet increasing demands of the national and international marketplace, producers will need to continue to supply increasing volumes of food more economically. The challenge of a sustainable approach will be for producers, consumers, and society as a whole to balance food production requirements with the need to conserve the land, water, and overall ecological integrity of the Prairies ecozone. Box 4.1 describes one current research project that measures the impacts of agriculture on the prairie ecosystem.

Box 4.1
South Tobacco Creek Project

The South Tobacco Creek Project was launched in 1990 as a 10-year cooperative investigation into the impacts of agriculture on land and water ecosystems in the Red River basin of southern Manitoba. Organizations involved in the project include the locally based Deerwood Soil and Water Management Association and various government agencies, research institutes, and universities.

Together, these groups are documenting the condition of the soil and the movement of water, soil, fertilizers, and pesticides through the drainage basin. Researchers are studying samples taken from two farm fields at the headwaters of Tobacco Creek, from stations downstream in Tobacco Creek, from Morris River, from the Red River, and, finally, from Lake Winnipeg, thus tracking contaminants in waters from source areas through the entire drainage system. As well, they are assessing the impact of agriculture on wildlife, including plants. The research so far has documented significant inputs of agrochemicals by long-range transport of air pollutants into the system from the corn belt in the United States. Applied and natural sources of nutrients have also been identified. As researchers gain a greater understanding of these sources and how the chemicals move through the system, they will be able to suggest alternative land use management practices. The costs and benefits of the various land management options will be evaluated so that rural and urban communities can make informed decisions to promote prairie ecosystem sustainability.

Water quality and quantity

Water performs many critical functions for all ecosystem components of the Prairies ecozone. Most of the water systems in the ecozone have been modified and developed. Reservoirs have been constructed on virtually every major river system to supply water, prevent flooding, and generate power (Box 4.2).

Agriculture is the largest industrial user of water in the Prairies ecozone. Water is drawn for irrigation, as well as for livestock, dairy, feedlot, and other farm operations. Estimated annual water use for irrigation remained constant between 1986 and 1991. In this period, the area irrigated increased by a mere 2%, far less than the 35% increase between 1981 and 1986. A variety of factors have contributed to this slower rate of growth, including unusually wet summers and improvements in delivery and irrigation application systems. Box 4.3 provides one example of a multipartner irrigation project that shows how environmental considerations can be included in planning.

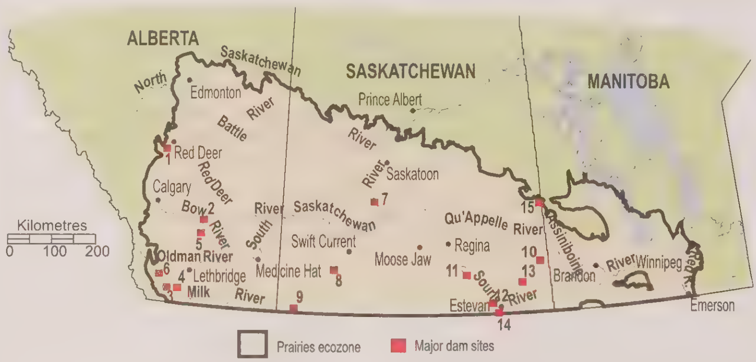
Box 4.2
Dams and their impacts

Dams and reservoirs are present on all of the major drainage basins in the Prairies ecozone (Fig. 4.B1). They are used primarily to store water for use during drought and to alleviate flooding during peak flows. The main developments of the 1990s have been the completion of the Rafferty Dam in 1992 and the Alameda Dam in 1994, both in southeastern Saskatchewan, and the Oldman Dam in 1993 in Alberta.

Construction of a new dam, the Pine Coulee Dam, on the Oldman River basin in the foothills of Alberta received Cabinet approval in January 1996, following approval by a joint federal–provincial hearing panel. Still at proposal stage are the Little Bow Dam and the Highwood River Diversion in Alberta, on tributaries of the Bow and Oldman rivers, respectively. An environmental assessment has been completed on this dam and diversion and awaits review by the provincial and federal regulatory agencies.

The construction of dams to develop new reservoirs can both generate and release a multitude of pollutants, including petrochemicals, solid wastes, and construction runoff. Dams and the resulting reservoirs also change aquatic and riparian habitat. Riverine habitat is replaced with a reservoir, whereas downstream habitat may be modified as a result of alterations in flood regime and trapping of sediment in the reservoir. Environmental assessments of dams and consequent conditions placed on their construction and operations are intended to minimize or mitigate these impacts.

Figure 4.B1
Major dams in the Prairies ecozone



Basin / Dam	Storage
Red Deer River basin	
1 Dickson Dam	(203)
Bow River basin	
2 Bassano Dam	(319)
Oldman River basin	
3 Waterton Dam	(173)
4 St. Mary Dam	(395)
5 Travers Dam	(326)
6 Oldman Dam	(490)
South Saskatchewan River basin	
7 Gardiner Dam	(9 360)
8 Duncairn Dam	(103)
Milk River basin	
9 Altawan Reservoir	(10)
Souris River basin	
10 Moosomin Lake	(11)
11 Weyburn Dam	(16)
12 Rafferty Dam	(394)
13 Alameda Dam	(106)
14 Boundary Reservoir	(61)
Assiniboine River basin	
15 Shellmouth Dam	(477)

(no.) = storage capacity in cubic decametres

Source: Geographical Analysis Team, Ecological Research Division, Environmental Conservation Service, Environment Canada, Regina.

Thermoelectric power generation constitutes the second largest demand on water withdrawal in the Prairies ecozone. Hydroelectric power generation does not withdraw water, although the water displacement of this activity has significant impacts on both aquatic and terrestrial life. Alberta produces most of its electric power from thermal sources. Manitoba produces almost all of its electricity from hydro plants, relying on some thermal energy. Saskatchewan has a mix of thermal stations and hydro plants. Through recycling, recently constructed thermal power plants have reduced the use of water. In 1991, thermal power plant water use was lower than in the census years 1976, 1981, and 1986, through the combination of higher flows in the Saskatchewan River system, lower demands for power, and replacement of older power plants with more efficient ones.

Municipalities extract relatively small amounts of water throughout the year, with higher demands during the summer. Water withdrawals for public use include domestic and commercial consumption, street cleaning, fire fighting, irrigation of municipal parks, and public swimming pools. Municipalities may also provide water for industrial, agricultural, and thermoelectric power production purposes. In 1991, the Prairie Provinces Water Board estimated that the average per capita use of public water in the Prairie provinces was 511 L/d, 7% lower than in the 1986 census year. This average can vary greatly between communities, depending on climate differences, the mix of uses, household and lot sizes, income brackets, age and condition of distribution systems, and water charges. Billing customers based on their actual water use contributes directly to water conservation. For example, Avonlea, Saskatchewan, a community of 400, installed meters in 1990; total water use dropped by 40% the following year and has remained 30% lower ever since.

Water conservation may become an increasingly pressing necessity. Recently, atmospheric researchers have concluded that some degree of climate change is probable, which means that natural annual water flows may decrease in the future

(see also Chapter 15). Seasonal shifts in precipitation and the time of freeze-up and breakup, along with long-term changes in temperature and evaporation, will contribute to changed annual discharges of rivers. Studies have indicated that if precipitation remains constant, a mean annual temperature increase of 1°C could decrease annual runoff volumes by between 5% and 15% (Nkemdirim and Purves 1994). Conserving water can improve the adequacy of existing surface water supplies and thus reduce the need to impound or otherwise regulate the natural flow of streams, leaving them as natural wildlife habitat and for recreational uses.

Eutrophication is possibly the single most important issue concerning water quality in the Prairies ecozone. Eutrophication is caused by the addition of nutrients, chiefly phosphorus and nitrogen, to water bodies. The abundance of these nutrients causes blooms of algae, growth of aquatic weeds, strong odours, cloudy water, and oxygen depletion. Most Prairie surface waters experience some degree of natural eutrophication. However, nutrient amounts are augmented by point source pollution, such as municipal sewage from urban areas and industries. Approximately 1 billion litres per day are returned to sewage systems for treatment and disposal (Wood 1995). Nutrients also come from non-point sources, chiefly associated with agriculture, such as runoff from fertilized lands and livestock feedlots.

Some reservoirs and lakes in the ecozone are receiving large amounts of these nutrients, increasing the likelihood of eutrophication. Total phosphorus entering Lake Diefenbaker exceeds the amount leaving the lake by a factor of 26 to 1 (Wood 1995). The upper reaches of the lake have become highly eutrophic, although the main body of the lake has yet to show signs of eutrophication. Studies have shown that the southern portion of Lake Winnipeg has reached a eutrophic state (Crowe 1972, 1973; Kling 1994). Nitrogen loads in the Red River at the U.S. border totalled over 5 000 t annually between 1989 and 1993, among the highest of all rivers in the ecozone, whereas phosphorus loads were at about 1 000 t (Wood 1995).

Box 4.3
Blood Tribe Indian Reserve: a vision comes to pass

The Blood Tribe Irrigation Project offers a working example of environmental and economic integration — of sustainable development in action. The Blood Tribe Indian Reserve occupies about 130 000 ha of land in southwestern Alberta near the city of Lethbridge. Owing to the limitations to agriculture posed by the largely semiarid climate and the chinook winds common to the region, the Blood Tribe has long pursued the opportunity to develop irrigation.

In 1989, the band signed the Blood Tribe Irrigation Project Agreement with the governments of Canada and Alberta. A tripartite committee was established to oversee the implementation of the project, which will cost an estimated $60.8 million (1988) and will be developed in stages over about 12 years. By the end of 1996, three of the project's six phases will have been constructed, irrigating 3 100 ha of the 7 430 ha that will eventually come under irrigation.

A key objective of the committee was to develop the project in an environmentally responsible manner. Following an environmental assessment, mitigation measures were incorporated into the project design, and an extensive monitoring program was implemented to enable early identification of potential problems, particularly canal seepage issues. Environmental enhancement opportunities are also being explored, including development of wildlife habitat, improved quality of rural domestic and livestock water supply, shelterbelts to control wind erosion, and integrated land use planning. The project is expected to create long-term employment and stimulate future value-added activities for the band, while minimizing environmental impacts.

Although concentrations of total nitrogen and total phosphorus in the six interprovincial rivers in the Prairies ecozone (South Saskatchewan, Qu'Appelle, Red Deer, Battle, North Saskatchewan, Assiniboine) are fairly similar (0.8–1.4 mg/L for nitrogen and 0.1–0.2 mg/L for phosphorus), the amounts of these nutrients entering the rivers, or nutrient loads, vary widely. Amounts of nitrogen entering the North Saskatchewan River were by far the highest, at just over 8 000 t per year between 1989 and 1993. Nitrogen amounts entering the Red Deer River were a little over 4 000 t per year in this period, and nitrogen amounts entering the South Saskatchewan River were 2 000 t per year. These three rivers also accounted for the greatest annual amounts of phosphorus, at 2 000 t in the North Saskatchewan, 1 000 t in the Red Deer, and a little less than 1 000 t in the South Saskatchewan (Wood 1995).

The overall municipal contribution to water pollution is on the decline. In the past five years, treatment systems in several major and smaller urban centres have undergone significant improvements (Fig. 4.5). These improvements, however, are partially countered by growth in the urban population. After a phosphorus removal system was installed in Calgary in 1983, amounts entering the Bow River from Calgary immediately decreased by 80%. However, total amounts increased by 20% over the subsequent five-year period (Sosiak 1990). An innovative means of using municipal effluent to agriculture's advantage is outlined in Box 4.4.

Salinization is another major concern for water quality in the Prairies ecozone. Highly salinized water is a natural characteristic of most Prairie drainage systems. However, salinization can be indirectly increased by human activity, and extremely high salinity can make water unsuitable for both human use and agricultural applications. Salinity develops primarily in the form of sulphates of sodium, magnesium, and calcium (Eilers 1995). Saline lakes are defined as those having concentrations of dissolved salts above 3 g/L (Wood 1995). Salinity increases in closed drainage systems where runoff is trapped, resulting in

the accumulation of soluble salts. High salinity in the innumerable shallow-water seeps and potholes in the Prairies ecozone results from the seepage of saline shallow groundwater (Hammermeister and Anderson 1992). In larger basins, increased salinity is typically due to evaporation exceeding precipitation (Last 1992; Campbell et al. 1994).

Some experts have observed a substantial increase in the salinity of many saline lakes in the Prairies ecozone over the long term (Hammer 1986). A fourfold increase in concentrations of total dissolved solids occurred in Big Quill Lake between 1925 (15 g/L) and 1985 (60 g/L). Salinization of Redberry and Manitou lakes increased by 50% over the same period. These increases have occurred as water that would have flowed into these lakes has been redirected for agriculture or diverted by dams (Hammer 1986).

No observable trends in salinity or total dissolved solids were noticed in the ecozone's interprovincial river basins during the period 1972–1993, despite the widespread droughts in the late 1980s and early 1990s (Prairie Provinces Water Board 1995a, 1995b). Concentrations of total dissolved solids in the six interprovincial basins as well as in the international basins (Red, Souris, Poplar, and Milk) typically range from less than 300 mg/L (in the Red Deer) to slightly over 1 000 mg/L (in the Souris), with values as high as 1 500 mg/L in the Qu'Appelle (Prairie Provinces Water Board 1995a).

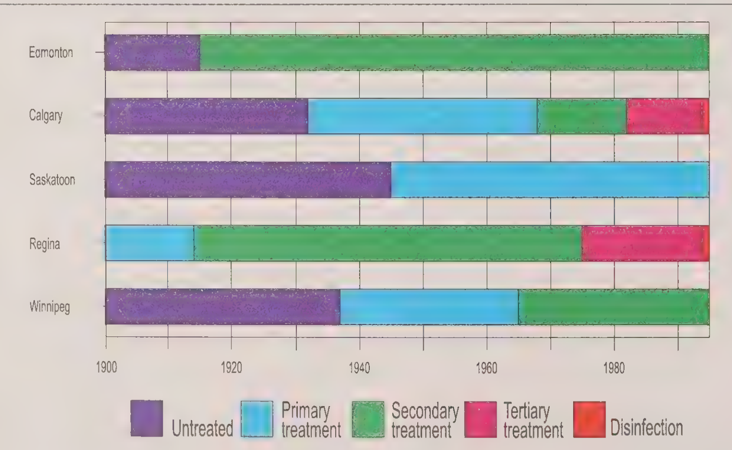
The Canadian drinking water quality guideline for levels of total dissolved solids (500 mg/L) has been exceeded on the Red, Souris, Battle, and Qu'Appelle rivers. The Red River was particularly affected during the droughts of the 1980s and early 1990s. The number of days when the guideline was exceeded dropped from 257 in 1990, during the height of the drought conditions, to 74 in 1993 (International Red River Pollution Board 1994). The major contributor to salinity in the Red River has been saline groundwater from subcropping formations of Cretaceous and Ordovician age (Strobel et al. 1994). At times, concentrations of dissolved solids in these groundwaters exceed 5 000 mg/L (Strobel and Haffield 1995).

Pesticides also pose a concern for water quality owing to their potential to contaminate groundwater and surface water supplies. Uncertainty also exists over their effects on biota, including humans. Eighty-five percent of the pesticides sold in the Prairies ecozone are herbicides, used primarily for the control of broadleaf weeds and wild grasses. In the most recent federal survey of pesticide sales (1990), the top-selling herbicides by weight in the three Prairie provinces were (not in order) 2,4-dichlorophenoxyacetic acid (2,4-D), triallate, trifluralin, 2-methyl-4-chlorophenoxyacetic acid (MCPA), glyphosate, and bromoxynil, all exceeding 1 000 t annually (Agriculture Canada and Environment Canada 1993). The amount of each pesticide sold varies yearly according to demand, economic trends, and prices.

Insecticides account for only 10% of the pesticides sold in the ecozone (Agriculture Canada and Environment Canada 1993). A survey of over 118 000 records from a federal water quality database during the period 1971–1988 showed that the nine most frequently detected pesticide residues were alpha-hexachlorocyclohexane (HCH), 2,4-D, lindane (gamma-HCH), MCPA, atrazine, diclorprop, picloram, disulfoton, and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Production of 2,4,5-T was discontinued in 1985, and its use became illegal in 1990. The remaining 52 pesticides were detected in less than 2% of the samples taken. Although the Canadian Water Quality Guidelines for protection of aquatic life were exceeded on numerous occasions, the Guidelines for Canadian Drinking Water Quality were not exceeded (Integrated Environments 1991; CCME 1994). Aquatic life guidelines are exceeded more commonly because they are several orders of magnitude lower (in the nanogram per litre range) than those for drinking water (in the microgram per litre range) (Wood 1995). For unknown reasons, detections of alpha-HCH and lindane declined to zero by the mid-1990s, even though sales of lindane doubled (Wood 1995).

For the 27% of the Prairies ecozone population who live in rural areas, drinking water is drawn largely from groundwater wells and dugouts. Research suggests that nitrate contamination of groundwater supplies is fairly common in the ecozone and that nitrate concentrations frequently exceed drinking water guidelines. There are over 100 000 dugouts in use in

Figure 4.5
Sewage treatment in cities of the Prairies ecozone, 1900–1995



Source: Environmental Conservation Service, Environment Canada.

the Prairie provinces (Corkal and Peterson 1994). Their water becomes contaminated as a result of high nutrient levels, accompanied by prolific phytoplankton (algal) growth, the presence of bacteria and parasites (*Giardia*), and elevated nitrate and pesticide levels. Algal growth and bacteria present the most serious threats to the water quality of dugouts (Wood 1995). A recent survey in Alberta found that water in 53% of dugouts did not meet the microbial guidelines contained in the Guidelines for Canadian Drinking Water Quality, compared with 7% of wells (Wood 1995). Peterson (1989) estimated that, to counteract water contamination, about 25% of farms in Saskatchewan use carbon filtration for domestic water supplies, another 25% use carbon filtration with chlorination for bacteria and parasites, and the remaining 50% use no treatment at all.

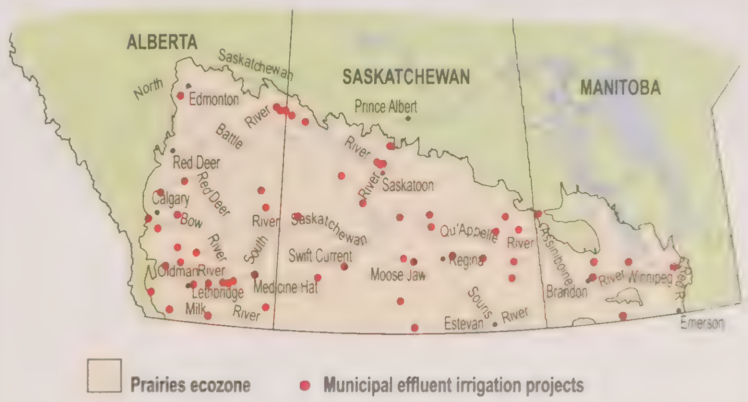
Water quality and water quantity are both recognized as important elements in achieving sustainability on the Prairies, and both are being addressed by governments in their responses to water management. Specific actions are outlined below in the section entitled "State of the environment and sustainability: society's response."

Box 4.4
Effluent irrigation

Effluent irrigation, the application of treated effluent to cropland, is a recent and increasingly accepted practice in Canada. This technology has benefits at both ends of the process. For one, it provides a solution for municipal, industrial, and agricultural effluent disposal; the low flow rates of Prairie rivers and streams and the effects on downstream water users or fish and wildlife pose limits to conventional disposal methods. Second, the increased moisture of effluent irrigation can increase crop yields, allow for a broader range of crops, and reduce risks due to drought. The nutrients in effluent can also provide a fertilizing benefit not normally found in irrigation water.

The effluent from 65 Prairie communities, ranging from tiny hamlets to the city of Moose Jaw, is now used to irrigate more than 5 500 ha (Fig. 4.B2). The potential for future effluent irrigation is significant. Approximately half of the urban communities on the Prairies produce effluent suitable for irrigation, which means that more than 100 000 ha could be irrigated in a sustainable manner. The challenge is to ensure that the effluent is compatible with the land being irrigated to avoid environmental damage. Heavy metal contamination, for example, is a potential concern.

Figure 4.B2
Municipal effluent irrigation projects in the Prairies ecozone



Source: Geographical Analysis Team, Ecological Research Division, Environmental Conservation Service, Environment Canada, Regina

Impacts of landscape alteration on biota

Over the past 100 years, the variety of species, or biodiversity, of the Prairies ecozone has been greatly reduced as a cost of agricultural expansion and the economic prosperity this industry has provided (see Chapter 11). Much of the native grassland has been fragmented or eliminated, with corresponding decreases in native animal and plant life (Alberta Forestry, Lands and Wildlife 1991). In recent years, landowners and government agencies have launched or augmented efforts to reverse this trend.

By 1995, 37 species of birds, mammals, and plants that inhabit the Prairies ecozone had been placed on the List of Species at Risk in Canada. The list is compiled by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Table 4.6). Species are classed according to one of five categories, beginning with extinct, then, in decreasing order of risk of extinction, extirpated (extinct in Canada but existing elsewhere), endangered, threatened, and vulnerable. The COSEWIC list does not include invertebrates.

Since 1987, government agencies, universities, and nonprofit groups have worked together under the umbrella of RENEW (the Committee on the Recovery of Nationally Endangered Wildlife) to develop programs to maintain or increase population levels of certain species at risk. Their teams work to determine the status of many species of concern and to recover species already on the COSEWIC list.

Although there have been some successes in the recovery of endangered species in the Prairies ecozone, such as the downlisting of the Ferruginous Hawk from threatened to vulnerable, other species, such as the Burrowing Owl, remain in jeopardy (Box 4.5). The Piping Plover, a small migratory shorebird, is in an apparent noncyclical decline, with extirpation likely to occur in about 80 years if population

trends are not reversed. Grassland birds are also declining. The Sprague's Pipit shows substantial declines, averaging 4.6% per year, and the Western Meadowlark declines an average 1.9% per year.

By contrast, duck populations have improved in the ecozone since the record low levels of the 1980s. Waterfowl surveys have shown a steady increase in the numbers of ponds available for waterfowl and a corresponding increase in the numbers of ducks (Fig. 4.6). This trend is attributable to improved water conditions, the maintenance of restrictive hunting regulations, and implementation of the North American Waterfowl Management Plan (NAWMP).

The NAWMP is a habitat restoration program that was signed in 1986, when public and private agencies in Canada and the United States joined forces to rebuild waterfowl populations. The Prairie Habitat

Table 4.6
Wildlife species in jeopardy in the Prairies ecozone, 1995

Current COSEWIC status	Group	Species	Trend between 1990 and 1995
Extinct	Birds	Pigeon, Passenger	Unchanged
Extirpated	Mammals	Bear, Grizzly (Prairie population) Ferret, Black-footed Fox, Swift	Uplisted in 1991 Unchanged Unchanged
	Birds	Prairie-Chicken, Greater	Uplisted in 1990
Endangered	Birds	Falcon, Anatum Peregrine Owl, Burrowing Plover, Mountain Plover, Piping Thrasher, Sage	Unchanged Uplisted in 1995 Unchanged Unchanged Added to list in 1992
	Plants	Lady's Slipper, Small White Mouse-ear-cress, Slender Orchid, Western Fringed Prairie	Unchanged Added to list in 1992 Added to list in 1993
Threatened	Mammals	Bison, Wood	Unchanged
	Birds	Shrike, Loggerhead (Prairie population) Sparrow, Baird's	Added to list in 1991 Unchanged
	Plants	Flag, Western Blue Spiderwort, Western Verbena, Sand	Added to list in 1990 Added to list in 1992 Added to list in 1992
Vulnerable	Mammals	Dog, Black-tailed Prairie Rat, Ord's Kangaroo Wolverine (Prairie population)	
	Birds	Bittern, Least Bluebird, Eastern Curlew, Long-billed Hawk, Cooper's Hawk, Ferruginous Owl, Great Grey Owl, Short-eared Swan, Trumpeter Tern, Caspian	
	Reptiles	Lizard, Eastern Short-horned Snake, Eastern Yellow Bellied Racer	
	Fish	Chub, Silver Shiner, Bigmouth	
	Plants	Aster, Western Silver-leaf Locoweed, Hare-footed Soapweed	

Source: Adapted from COSEWIC (1995).

Joint Venture, the largest of 32 regional habitat programs under the NAWMP, sets out programs aimed at restoring habitat to maintain waterfowl populations in the Prairie provinces at 1970s levels (spring breeding numbers of 17–20 million birds). From 1986 to 1995, the venture secured almost 0.32 million hectares of wetland and surrounding habitat in the Prairie provinces, 22% of its overall objective of 1.5 million hectares.

According to a study done in 1993, farmers participating in NAWMP programs receive considerable compensation from the venture to cover costs of foregone agricultural production. They also benefit from long-term improvements in farmland management. Community business activities benefit from improved agricultural production and tourism (Bjonback 1995).

In 1994, the NAWMP objectives were updated to encourage policies that make agricultural land use more sustainable. The program's revised vision includes managing on an ecosystem scale, conserving biological diversity, expanding participation, and integrating wildlife conservation with sustainable economic development. As well, in 1994, Mexico signed the NAWMP, to join with government and private interests in Canada and the United States in a continental sustainable development program to restore waterfowl and wetland resources.

Landowners and agencies have also launched several projects in the ecozone to reinvigorate riparian zones, the lush and heavily vegetated areas along creeks, rivers, and streams. Human activities have degraded many of these zones. In the Prairies ecozone, the water that seeps into these areas creates habitat that supports more numerous and varied plant and animal species than does the adjoining higher ground. Riparian zones limit soil erosion, filter pesticide residues and nutrients from runoff water, reduce flooding, and provide fish habitat. One initiative launched in Alberta is the Riparian Habitat Project, funded by the Canada–Alberta Environmentally Sustainable Agriculture Agreement and spearheaded by Trout Unlimited of Canada, the Alberta Cattle Commission,

Box 4.5
Burrowing Owl

The number of Burrowing Owls in Canada continues to decline despite the efforts of a multiagency recovery team (several papers in Holroyd et al. 1987, 1991, 1993; Wellicome and Haug 1995). The species is classified as endangered on the List of Species at Risk in Canada.

Burrowing Owls breed in Prairie Canada and in the interior of British Columbia. They nest in heavily grazed pastures in the abandoned burrows of digging mammals such as Badgers, foxes, and Ground Squirrels. The owls forage for small mammals (mice and voles) and insects (grasshoppers and beetles) in adjacent grasslands and roadsides. Their winter distribution is not well-known but is thought to be in the southern United States or northern Mexico.

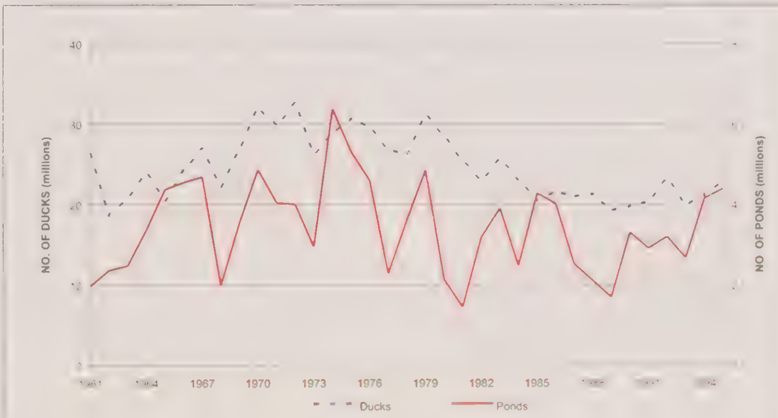
Surveys indicate that the owl's population is on a steady decline. The breeding population in Canada in 1994 was estimated at 1 010–1 685 pairs (Wellicome and Haug 1995), compared with 2 500 pairs in 1990 (Haug and Didiuk 1991) and 3 000 pairs in the 1970s (Wedgewood 1978). The estimates are based on systematic surveys and landowner reports (Dundas 1993; Scobie 1993).

Habitat loss is probably the single major cause of reductions in the number of owls that nest in Canada. Numbers continue to decline despite the efforts of Operation Burrowing Owl, a program that has recruited 748 landowners in Saskatchewan and Alberta to protect 37 768 ha of private land. In Saskatchewan, for example, 68% of Operation Burrowing Owl pastures that hosted Burrowing Owls in 1986 had no owls in 1993 (Dundas 1993).

Burrowing Owl reproduction on the Canadian prairies may be too low to maintain the population. With too few young produced each year and high mortality, on the Canadian breeding ground and possibly on migration and during winter, the outlook for this small owl is not encouraging.

Figure 4.6

Trends in the numbers of breeding ducks (all species) and ponds in western Canada, 1961–1995



Note: For total ducks, strata (or linear samplings) 12–40, 50, and 75–77 were used; strata 26–40 and 75–77 were used for total ponds.

Source: K. Dickson, Canadian Wildlife Service, Environment Canada, personal communication.

Table 4.7
Protected areas in the Prairies ecozone

Year	IUCN[a] categories: Strict nature reserve/wilderness areas: No. of sites	% of area	National parks: No. of sites	% of area	Natural monuments: No. of sites	% of area	Habitat/species management areas: No. of sites	% of area	Landscapes/seascapes: No. of sites	% of area	Managed resource areas: No. of sites	% of area	Total no. of sites	Total area protected (ha)
1960	0	0.00	26	0.96	1	0.00	35	0.18	16	0.20	69	1.73	147	1 384 245
1980	0	0.00	43	1.15	8	0.01	91	0.33	137	0.29	90	1.98	369	1 738 683
1990	6	0.02	47	1.24	16	0.03	119	0.51	159	0.33	90	1.98	437	1 851 186
1994	8	0.02	48	1.24	17	0.03	119	0.51	159	0.33	90	1.98	441	1 852 590

[a] World Conservation Union, formerly the International Union for the Conservation of Nature and Natural Resources.

Source: National Conservation Areas Database, State of the Environment Directorate, Environment Canada.

Box 4.6
Suffield National Wildlife Area

The Suffield National Wildlife Area (SNWA) is part of Canadian Forces Base Suffield, a military training range in southern Alberta. The area is home to a vast assortment of prairie wildlife, including many species classified as endangered or threatened on the List of Species at Risk in Canada. Although the SNWA was not created until 1992, the environmental sensitivity of the area has long been recognized. When the British army signed a contract in 1971 to conduct tank training, land recognized as precious wildlife habitat was set aside for protection.

In the early 1980s, the Canadian Wildlife Service suggested to the Department of National Defence that the environmentally sensitive lands on the base adjacent to the South Saskatchewan River be turned into a recognized wildlife protection area. In the early 1990s, with the implementation of the Green Plan, the Prairie Conservation Action Plan, and the National Wildlife Strategy, momentum developed to create a national wildlife area at Suffield.

On March 11, 1992, the Department of National Defence and Environment Canada signed a memorandum of understanding to create a national wildlife area on about 45 800 ha of the base. Biologists from the Canadian Wildlife Service, along with specialists from other agencies, are now gathering and interpreting information on the mixed-prairie ecosystem of the SNWA to develop an ecological land inventory. This inventory will provide information needed to address complex land use and resource development issues and will benefit day-to-day management and long-term planning in the SNWA and other similar mixed-prairie ecosystems.

Alberta's Land and Forest Services and Natural Resources Service (Alberta Environmental Protection), the federal Department of Fisheries and Oceans, and many other partners.

To preserve wildlife habitat, the federal, provincial, and territorial governments in Canada are committed to setting aside representative portions of the nation's ecosystems for conservation. Globally, the World Commission on Environment and Development estimates that meeting this objective will require protection of some 12% of the Earth's surface. While the federal government has endorsed this goal, it does not necessarily mean that 12% of each ecosystem in Canada needs to be protected. Rather, provincial/territorial and federal governments are trying to establish conservation areas that will represent self-sustaining ecosystems in each ecozone and the variations within them. By 1995, 441 protected areas had been established in the Prairies ecozone, totalling 1 852 590 ha (Table 4.7). Between 1990 and 1994, only four sites, totalling 1 404 ha, were added.

In recent years, each provincial government in the Prairies ecozone has launched programs to protect biodiversity and representative features of the ecozone. These include Alberta's Special Places 2000 Program, Saskatchewan's Representative Areas Network, and Manitoba's Natural Lands and Special Places Strategy. The Saskatchewan program calls for one large representative area in each of 11 ecoregions, plus a sufficient number of smaller representative areas to achieve full representation of ecosystem types in all 157 landscape areas that make up the 11 ecoregions. Under Manitoba's strategy, the protected land base has been increasing steadily since 1992. Four new northern provincial parks, totalling 2.1 million hectares, were designated in 1995, in one of the largest designations of land protection in the history of the campaign.

These protected areas are often islands of preservation within a landscape otherwise altered by human activity. However, even they are not exempt from the impact of human activity. Manitoba's Riding Mountain National Park, for example, attracts up to 400 000 visitors a year who engage in a host of outdoor activities. The infrastructure needed to support these activities fragments habitat and impacts on the ecosystem's functions and basic structure.

Similar pressures are present in many parks, such as Prince Albert and Elk Island national parks.

A current Canadian Wildlife Service workplan calls for the creation of 14 new national wildlife areas and the enlargement of nine others in the Prairies ecozone. Also proposed are the addition of two migratory bird sanctuaries and the enlargement of an existing one. In 1995, governments also renewed the five-year-old Prairie Conservation Action Plan (PCAP) to initiate PCAP II, a plan to preserve native prairie on both public and private lands. One of the chief accomplishments of PCAP I was the creation of the Suffield National Wildlife Area in Alberta (Boxes 4.6 and 4.7).

Box 4.7
Antelope Creek: comanagement in action

The Antelope Creek Ranch in southeastern Alberta is an excellent example of comanagement, in which several agencies that have a mutual interest in a property share in its management. A partnership of governmental and nongovernmental agencies purchased the 2 230-ha ranch near the town of Brooks in 1986. Years of continuous grazing had left the native range in poor condition. The partners saw an opportunity to apply management practices that would restore the range, improve wildlife habitat, and protect the integrity of the prairie ecosystem.

The partners estimated the number of cattle the range could support and worked to make sure this number was not exceeded. They delayed grazing until summer to allow adequate spring regrowth of native grasses and provided adequate rest periods following grazing for native range and tame pasture. Range conditions, productivity, and livestock numbers were carefully monitored. Over a six-year period, from 1987 to 1992, the range condition and productivity had improved to the point where the number of grazing cattle could be increased. The enhanced plant cover helped birds by providing better nesting sites than those available on the previously overgrazed range.

The Antelope Creek Ranch is on the road to recovery and shows the benefits of a planned range management program with specific goals for maintaining and improving the productivity of prairie rangeland. The ranch is used for on-site demonstrations of management techniques, and the partners have produced a videotape covering range management principles.

Box 4.8
Federal–provincial forestry agreements

A set of federal–provincial initiatives called Partnership Agreements in Forestry has been instrumental in setting new directions for forest management in the Boreal Plains ecozone. Between 1990 and 1992, the Canadian government signed new agreements with Alberta, Saskatchewan, and Manitoba to build upon the achievements of previous forest resource renewal accords. Funded by a $45 million investment from the federal government and $15 million from each of the three Prairie provinces, these agreements were intended to maintain and enhance the long-term health of the forest environment, which encompasses about 60% of the land area of Alberta, 46% of Saskatchewan, and 40% of Manitoba.

Research projects funded under the agreements have had a significant impact on forest management in the Boreal Plains ecozone. Projects included improving forest fire management capabilities and creating biological control processes to boost spruce regeneration. Work on alternative harvesting systems has led to the adoption of modified logging strategies. The experimental spreading of pulp sludge on agricultural land has provided Prairie farmers with a new source of soil nutrients, whereas forest product research has led to improved utilization of wood and fibre from Prairie forests. By the time the agreements expired in March 1995, nearly 1 500 projects had been undertaken across the Prairie provinces.

Boreal Plains ecozone

The practices and policies of natural resource management in the Boreal Plains ecozone are rapidly changing. To manage in a sustainable manner, all aspects of the natural environment, including resource values, are being considered in an integrated fashion prior to resource allocation (Saskatchewan Environment and Resource Management 1995). Industry and landowners have indicated an increased interest in participating in resource allocation decisions. The following section illustrates this new approach to resource management in the Boreal Plains ecozone. It also looks at changes in the aquatic environment — which is greatly affected by industry — and discusses the pervasive increases in human disturbances in the ecozone.

The Boreal Plains ecozone is endowed with considerable natural resources, which support industries such as agriculture and forestry. The impacts of these industries on the landscape and water constitute the main issues affecting the ecozone's environmental quality and potential for achieving long-term sustainability. Other important human activities affecting the Boreal Plains ecozone, covered in less detail here, include mineral and energy industries (see Chapter 11), hunting, and recreation.

Resource management

Recently, trends in forest management in the Boreal Plains ecozone have started to reflect a sensitivity to environmental concerns. New approaches have been developed to reduce or eliminate threats to the environment. The traditional forest management concept of sustained yield, or producing tree crops in perpetuity, is being supplanted with the concept of sustained ecosystem development and landscape management. Under this new

approach, forest managers recognize that the forest is much more than a group of trees; it is a holistic system with the mix and interdependencies of many components, including the flora, fauna, soil, water, and air.

Roughly half of the ecozone is deemed productive forestland. Large areas have been leased by provincial governments to private companies through a variety of forest management agreements for wood harvesting. Companies engaged in these agreements may be required to develop and follow management plans to ensure compliance with environmental guidelines and practices. Such plans are developed according to the characteristics of the terrain and forest type. For species that require full sunlight for regeneration, clear-cutting may be practised in variable-sized patches of irregular shape to preserve habitat diversity. Management plans may also include specifications for forest regeneration. The renewal of the forest may be ensured by providing seedbed for the new crop or by replanting in areas that fail to regenerate. Between 1986 and 1992, forest regeneration in Alberta increased from just over half to nearly 100% of the area harvested (Canadian Council of Forest Ministers 1992a).

Figure 4.7
Forest disturbance in the Boreal Plains ecozone

[a] Area with moderate to severe defoliation by insects.

Source: *Fire and harvest*: ESSA Technologies Ltd. (1993); Canadian Forest Service, Natural Resources Canada, Ottawa; *Pest*: W.J.A. Volney and C. Currie, Canadian Forest Service, Natural Resources Canada, unpublished data.

In an effort to encourage sustainable forest management, the Government of Canada signed agreements with all three provinces to carry out programs in intensive forest management, reforestation, and research on provincially and federally owned lands (Box 4.8). In another program, a network of model forests has been established by the Canadian Forest Service across the country to develop management techniques that balance resource uses and integrate environmental, social, and economic values. Decision-making is a key feature of the model forest programs. The Boreal Plains ecozone includes one such project in each of the three Prairie provinces. The Foothills Model Forest occupies about 2.5 million hectares in Alberta and includes Jasper National Park. Specific subprojects include assessing ecologically significant areas for possible protection and developing experiments in advanced harvesting and reforestation techniques. The Prince Albert Model Forest occupies 0.31 million hectares in central Saskatchewan. Working with Aboriginals as participants, this project aims to develop ecosystem-based forest management tools. The Manitoba Model Forest occupies a million hectares. This project explores the spiritual values of the forest by collecting legends and oral history from the region's First Nations' elders.

Forest fires continue to be a dominant natural disturbance in the boreal forest, despite advances in fire prevention, detection, and suppression. Large areas burned in the late 1980s when summer precipitation was below normal (Hirsch 1991), showing the enormous difficulties of controlling fires under dry conditions (Fig. 4.7). New, specialized, remote heat and

lightning sensing equipment is being used to help locate and control fires before they spread over large areas.

The forests are also affected by native forest insects and diseases. Outbreaks of Spruce Budworm have affected extensive areas of spruce and fir forests. Other insects, such as the Forest Tent Caterpillar, have defoliated and damaged large areas of Trembling Aspen stands in peak years. Defoliation by this species alone totalled 3.7 million hectares in 1988 and 2 million hectares in 1989. Since then, the area damaged has declined, with only 46 000 ha being defoliated in 1992 (Bjonback 1995). The recent decrease in Forest Tent Caterpillar defoliation is due to the cyclical nature of infestations by this species. Infestation increases during dry, warm springs and declines quickly when late frosts or other weather events occur that influence the insect/host phenology (timing of egg hatch and host leaf development).

Changes in the aquatic environment

Water resources are abundant in the Boreal Plains ecozone. The local residential impact on water quality is low compared with that of more populated areas. However, variations in the soils, land cover, and land uses in the ecozone make water quantity and quality highly variable. Research is being conducted into the impacts on aquatic ecosystems of increased economic activity in recent years, particularly by the forest products industry (Box 4.9).

The majority of the surface waters in the Boreal Plains ecozone are part of the Peace/Athabasca/Slave, Saskatchewan, or Beaver river watersheds. Most of the flow in the Peace and Athabasca rivers originates outside the ecozone as snow and glacial meltwater from the Omineca Mountains of north-central British Columbia (Peace River) and the Columbia Icefields of Jasper National Park (Athabasca River). As a result, natural flows show high seasonal variation, being high in spring and summer and low in winter. The nature of flows from mountain streams is that they tend to peak later and stay higher longer than streams originating from the Prairie landscape. The Peace–Athabasca Delta is one of the largest freshwater deltas in the world and forms an invaluable ecological resource (Peace–Athabasca Delta Implementation Committee 1983). Over two-thirds of the average annual flow of the Peace River, however, has been regulated since the construction of the W.A.C. Bennett Dam and filling of Williston Reservoir (1968–1972). The dam has affected water levels as far downstream as the Peace–Athabasca Delta as well as in the Slave River, which drains the Lake Athabasca drainage basin. Lakes in the Boreal Plains ecozone were formed as glacial meltwater-filled depressions. The smaller lakes are used primarily for recreation in the south

Box 4.9
Northern River Basins Study

The Northern River Basins Study was initiated in 1991 in response to public concern over the rapid expansion of the forest industry in the Peace, Athabasca, and Slave river basins. The objectives of the study were to collect and interpret data for use in planning and management of aquatic ecosystems in the study region and to determine means of predicting the possible impacts of future economic development, while ensuring that the public was informed regularly of the study's progress.

The study was administered by a 25-member board consisting of Aboriginal leaders, government representatives, and members of the environmental, health, education, agricultural, and industrial sectors. An independent science advisory committee oversaw the scientific integrity of the research. The board held community gatherings to take into account public comments, concerns, and suggestions regarding development of the river systems. The governments of Canada, Alberta, and the Northwest Territories contributed $11.5 million to the study, which ran from fall 1991 until spring 1996 (Fig. 4.B3).

Figure 4.B3
General area of the Northern River Basins Study

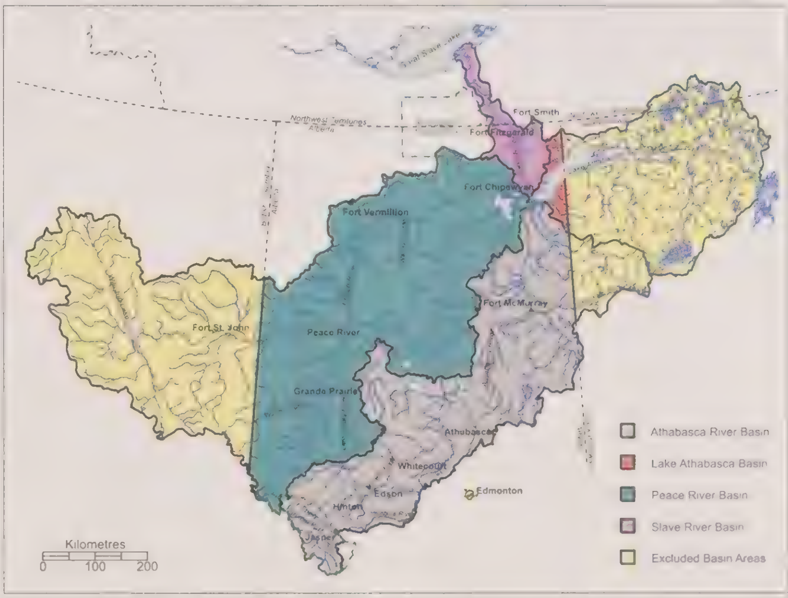
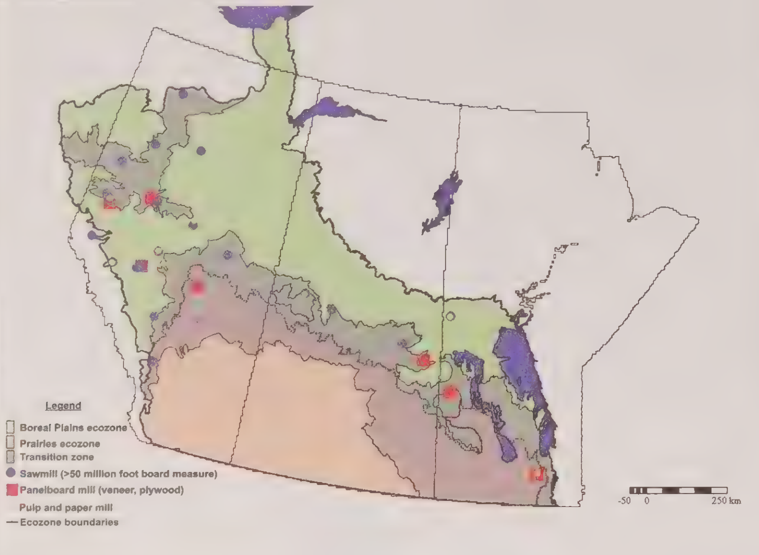


Figure 4.8
Forest industries in the Central Plains



Source: Environmental Conservation Service, Environment Canada.

and for subsistence fishing in the north. The importance of the larger lakes, such as Lesser Slave Lake, for the commercial fishery has declined in recent years.

The acidification effects of sulphur dioxide and nitrogen dioxide emissions, which emerge from oil sands developments and pulp mills, constitute one of the greatest impacts on the water quality of acid-sensitive lakes and rivers in the western portion of the Boreal Plains ecozone. Alberta's extensive oil and pulp mill processing makes it the third largest producer of sulphur dioxide in Canada and the largest producer in northwestern North America. However, emissions are only 35% of those in Ontario and Quebec (McDonald et al. 1993).

In the expanding forest industry, pulp mills have become one of the biggest users of water resources and a large source of effluent. Alberta has seven pulp mills, five on the Athabasca River basin and two on the Peace River basin (Fig. 4.8). Between 1973 and 1992, total pulp mill production in Alberta increased from about 1 000 t/d to about 4 500 t/d, and again to 6 000 t/d in 1993 and 1994 (Fig. 4.9).

The two processes commonly used to produce pulp in Alberta, chemi-thermo-mechanical and bleached kraft, affect water quality. Although most of the waste produced during pulping is nontoxic, its decomposition by bacteria creates a huge biochemical oxygen demand (BOD) on the river ecosystem. BOD, primarily from microbial decomposition of organic matter, may sometimes completely remove dissolved oxygen from the lower depths for extended periods during the summer or winter. As a result, fish may die in a phenomenon called summerkill or winterkill. However, the Northern River Basins Study, undertaken in 1991–1996, revealed significant improvements in pulp discharges to Alberta surface waters between 1957 and 1994 — during a period when pulp production increased nearly 10-fold. BOD discharges from Alberta pulp mills since 1992 have levelled off at about 6 000 kg/d, a substantial decrease from the nearly 15 000 kg/d in 1973 and 30 000 kg/d in 1957 (Fig. 4.9). Owing to stringent standards, the seven pulp mills in Alberta today have combined discharges, particularly BOD, that are significantly less than the discharges recorded from the single mill that existed in 1957.

Pulp mill effluent also affects water quality in the form of compounds called chlorinated organics, which are produced when chlorine is used in bleaching pulp to produce high-quality white paper. Although most chlorinated organics pose little or no environmental risk, certain families of these compounds, known as dioxins and furans, are some of the most toxic substances known. At sublethal doses, chlorinated organics are linked to deformities, reproductive failure, and abnormal liver enzyme activity in fish. Process changes by industry in response to new federal regulations have virtually eliminated furans and dioxins from pulp mill effluent and significantly reduced chlorine use (see Chapter 16).

Chlorinated organics accumulate in fish tissue, posing a health risk to those eating fish caught even thousands of kilometres downstream (Carey et al. 1993). The presence of chlorinated organics is determined by measuring emissions of adsorbable organic halides (AOX), which originate in pulp mill effluent. AOX discharges from Alberta mills were found to be 1 400 kg/d in 1993 and 1 000 kg/d in 1994, a considerable decrease from the 7 500 kg/d levels of 1973 (Fig. 4.9). These decreases are due to reductions in the amount of chlorine used in the kraft process. All of the kraft pulp mills (with the exception of the Diashowa mill on the Peace River) have gone to 100% chlorine dioxide substitution for chlorine in their bleaching sequence.

Governments and industry have worked jointly to control pollution at its source and to develop new pulp mill technologies. In 1992, new federal regulations were developed for pulp and paper effluents under the *Fisheries Act*. All the pulp and paper mills in the Boreal Plains ecozone are generally in compliance with these regulations, although allowable limits are occasionally exceeded. One mill in Manitoba required a "transitional authorization" to allow time for it to come into compli-

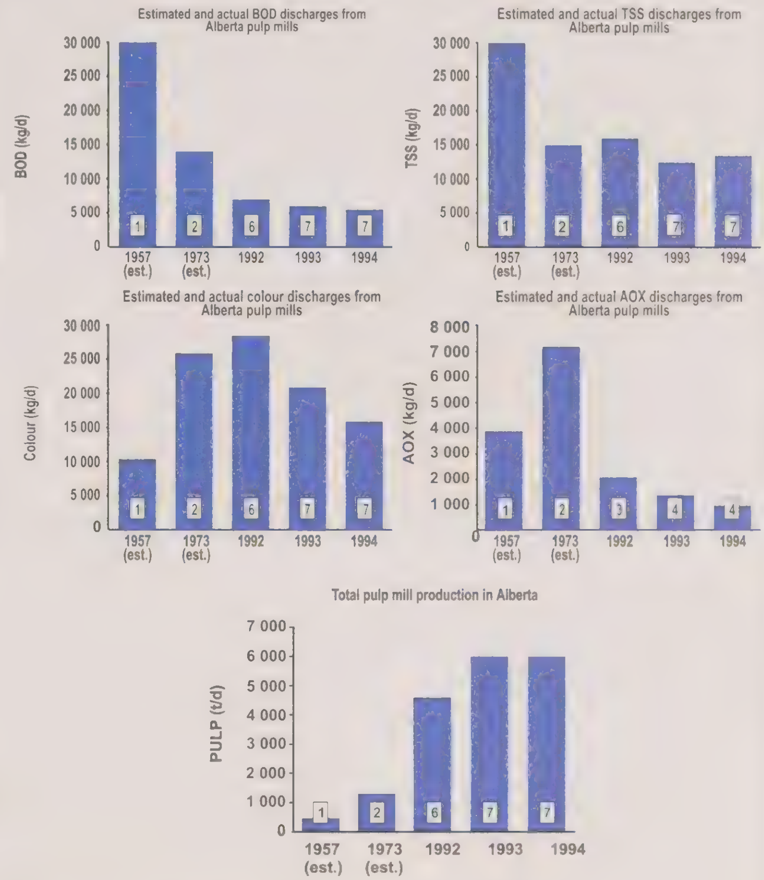
ance. Construction of a secondary treatment facility was completed in the fall of 1995, bringing the mill into line with the regulatory limits. The Millar Western Pulp Mill near Meadow Lake, Saskatchewan, is not regulated under the *Fisheries Act*. This state-of-the-art pulp mill, which went into production in 1992, produces no liquid effluent. The mill was designed to minimize water use, and all effluents are treated and recycled by the mill.

Agricultural practices that affect water quality in the ecozone include contamination of surface water and groundwater by pesticides, nutrient loading from fertilizers and livestock manure, and increased water turbidity from soil erosion. Pesticides have been detected in fish and other aquatic organisms years after their use was discontinued or banned in Canada. Sales of the insecticide toxaphene were discontinued in 1983; however, levels of the chemical found in Burbot livers caught in the Slave River in 1992 led Health and Welfare Canada to recommend that the public limit consumption of this species (Peddle 1995). In samples of Alberta surface waters taken between 1971 and 1993, four herbicides were detected in more than 1% of samples: 2,4-D in 19%, the discontinued pesticide 2,4,5-T in 5%, atrazine in 3%, and bromacil in 3%. The three insecticides detected in more than 1% of samples were alpha-HCH in 69%, lindane in 19%, and dursban in 2%. Guidelines for protection of aquatic life exist for all of these substances except bromacil and dursban (Dunsmore 1995). Many newer pesticides are now being used in such minute quantities that they are not detectable by current monitoring technology.

Municipal effluent from domestic sewage and urban runoff present significant threats to water quality, and rivers that run through major urban centres often show high levels of nutrients and bacteria. Industrial pollutants also compromise water quality, causing increases in water temperature, metal concentrations, and organic matter content and introducing a wide range of chemicals (Mitchell 1994a). Despite these impacts, the river water quality has improved considerably since the first surveys in the 1950s (Mitchell 1994b).

Figure 4.9

Pulp mill discharges to Alberta surface waters and total pulp mill production, 1957–1994



Note: The total number of mills contributing to discharges/pulp production is given within each bar.

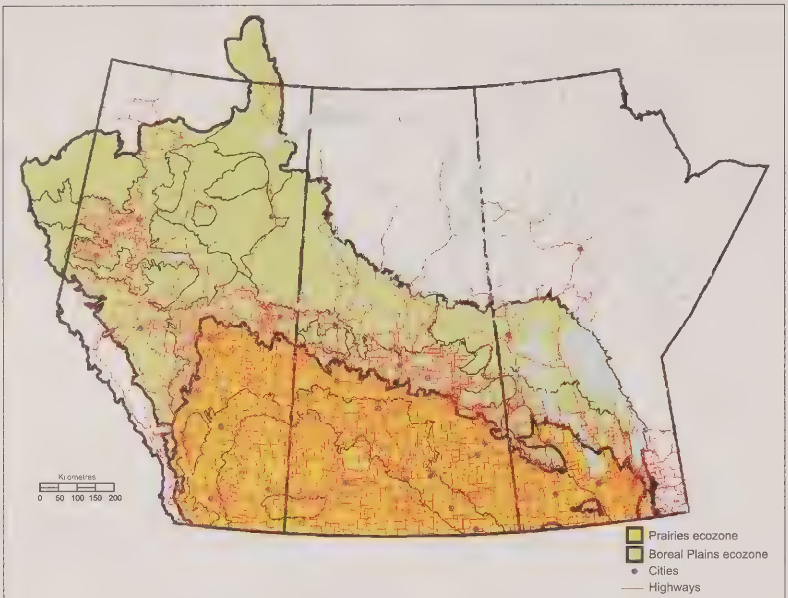
BOD = Biochemical oxygen demand
AOX = Adsorbable organic halides
TSS = Total suspended solids

Source: Environmental Regulatory Services and Water Resources Services, Alberta Environmental Protection.

Oil and gas fields in the ecozone are located primarily in Alberta, occurring in each of the province's four major drainage basins: Judy Creek – Swan Hills, West Pembina, Drayton Valley, and Cold Lake regions. Accidental oil spills and disposal of saline water from deep groundwater pockets produced during oil extraction pose a risk to water quality (MacDonald 1990; Prairie Provinces Water Board 1995b).

There are many small petroleum refineries on the Peace and Athabasca rivers, but these use only small amounts of water and result in minimal or no waste discharges. Their effluent is made up of stormwater runoff, cooling water, and process effluent. Heavy metals (chromium, copper, nickel, and zinc) are also present, but at low concentrations. Natural gas processing plants produce effluent containing many organic compounds, but wastewater volumes are low (Dunsmore 1995).

Figure 4.10
Cities/towns and major highways in the Central Plains



Source: Environmental Conservation Service, Environment Canada.

Mining activities in the Boreal Plains ecozone are largely associated with the extraction of coal in the Rocky Mountain foothills of Alberta and British Columbia. Some coal extraction is centred around Howell Creek in the Peace River basin, the McLeod and Pembina rivers in the Athabasca River basin, and Lake Wabamun in the North Saskatchewan River basin. Both open pit and underground coal mines can affect the quality of receiving waters and can cause loss of fish habitat as streams are affected by mining developments.

Overall, water in the Peace and Athabasca rivers is considered essentially uncontaminated, although long-term data are scarce. Contaminants originating upstream in the Peace and Athabasca rivers show up in trace amounts in the Slave River. Although the Beaver River is considered generally pristine in quality owing to favourable natural conditions and lack of human activity in the headwaters, it does receive wastewater discharges prior to the point at which it crosses from Alberta into Saskatchewan. Government agencies are pursuing several recommendations for ongoing and future aquatic ecosystem protection and water management (Dunsmore 1995).

Human disturbances

The most recent and ongoing trend in human disturbances in the Boreal Plains ecozone is the increased rate of forest harvesting, especially of the previously little-used aspen stands. This increase is most apparent in Alberta, where the annual area of land harvested increased by 125% between 1975 and 1993.

Agriculture has also become a more widespread land use. Between 1971 and 1991, farmland increased by over 84 000 ha, to occupy about 16% of the total land area. The clearing of woodland for agricultural expansion has affected local drainage flow patterns, watercourses, and wetlands. Since initial cultivation, between 15 and 30% of the ecozone's soil organic matter has been lost (Acton and Gregorich 1995). However, as in the Prairies ecozone, sustainable agricultural practices such as conservation tillage and reduced summerfallow have recently been adopted. In the Boreal Plains ecozone, summerfallowing was reduced by about 53% between 1971 and 1991 (Bjonback 1995).

Expansions of forestry and agricultural activities have affected wildlife and wildlife habitat. Nine of the species on the COSEWIC List of Species at Risk in Canada inhabit the Boreal Plains ecozone: the Passenger Pigeon is extinct; the Grizzly Bear and Greater Prairie-Chicken are extirpated; the Anatum Peregrine Falcon, Burrowing Owl, Piping Plover, and Small White Lady's Slipper are endangered; and the Wood Bison and Loggerhead Shrike are threatened. Agencies have taken steps to reverse the fortunes of the bison under cooperative programs administered by the RENEW Committee. For example, the Wood Bison increased from 450 individuals in 1978 to over 3 000 in 1993.

Human activity is also putting a strain on fish populations, primarily through habitat degradation (including damage to shoreline vegetation) and overfishing. The slow decline of high-value fish stocks, particularly pickerel and Sauger, through both commercial and recreational fishing is a concern. However, no major trends in fish abundance are evident from commercial harvest data. Harvests of most of the heavily fished species were substantially higher in 1993 than in 1992 but returned to near 1992 levels in 1994. In 1994, harvests totalled approximately 1 700 t of pickerel, 1 200 t of Sauger, 800 t of pike, 600 t of mullet, and 350 t of perch. The pattern was reversed for whitefish, by far the most heavily harvested species in each of the three years. The 1994 harvest of whitefish was about 3 300 t, the same amount as in 1992, whereas the 1993 amount was about 2 700 t. These figures reflect fishing industry activity in response to market forces, including product price, fishing costs, and catch per outing. Therefore, they measure the harvests of fished populations, rather than their precise status.

Although habitat degradation has a less immediate impact on fish stocks than does harvesting, its long-term impact is equally significant. Habitat degradation may result from the construction of in-stream dams,

irrigation withdrawals, and livestock grazing along streambanks. The consequent disturbance of these streams reduces spawning and nursery areas and therefore reproductive success. Current research has yet to determine the impact of aspen harvesting on aquatic ecosystems. On the other hand, existing reservoirs are stocked by fisheries and wildlife officials and thus are a source for commercial as well as recreational fishermen.

Although human presence and its impact are difficult to quantify, Figure 4.10 shows the major cities and road networks as surrogate measures to illustrate the relative human presence distributed across the Central Plains landscape. Seemingly nonconsumptive recreational activities affect the landscape. Activities such as hiking and camping can impose considerable stress on ecological systems. Extensive hiking compacts forest soils, affecting plant growth by reducing oxygen and moisture levels in the soil. Human activities and presence may also influence species reproduction, composition, and diversity, population dynamics, and habitat use. Wildlife is of particular economic value to Aboriginal peoples, who rely on hunting, fishing, and trapping as primary sources of food. The preservation of wildlife has a broad range of economic, societal, and environmental values and benefits. Environment Canada estimates the total value of wildlife at $1.1 billion per year (Environment Canada 1993).

The transition zone

Human activities

Historically, the fertile soil of the transition zone's parkland area attracted many settlers who farmed the grasslands but not the forested bluffs. The first significant settlement was established in the Red River valley after the granting of about 30 million hectares of land in 1811 (Friesen 1984). Settlement and the breaking of new land proceeded much more rapidly after 1870, when the land was transferred to the Dominion of Canada. The forested areas were cleared later to add more acreage to farmsteads. The area of wooded lands on farmsteads decreased to a fraction of its former area between 1931 and 1981, and the remaining woodlands decreased by 50% between 1981 and 1986.

European influence in the southern part of the Boreal Plains ecozone began with the establishment of trading posts, such as The Pas, Cumberland House, Fort à la Corne, and Fort Edmonton. The rate of settlement lagged behind that of the prairies, as clearing the land was an arduous task. Much of the open arable land had been occupied by 1910 with the development of rail transportation.

Environmental trends

With the progression of land clearing in the transition zone and the large decrease in the areal extent of forested areas, wildlife habitat has been reduced both in quantity and in quality (Driver 1991). Only areas with sandy or peaty soils remain relatively unaltered. Little information is available to determine original areas of wetlands or to track wetland losses in the transition zone. Approximately 80–96% of the natural wetlands near Edmonton, Calgary, and Winnipeg have been so altered that they no longer function as wetlands. Most have been converted to agricultural uses, with about 5% being converted to urban uses and 5% to recreational uses (Environment Canada 1986). Recent wetland conservation programs, such as Prairie CARE, the Saskatchewan Heritage Marsh Program, and the Manitoba Heritage Marsh Program, are intended to reverse this trend (Cox 1993).

In recent years, the increased marketability of aspen logs has made harvesting the remaining aspen stands an economically viable activity. As a result, some woodlot owners are eliminating stands and converting the land to pasture or cropland. In Alberta, regulations came into effect in 1996 that require timber permits for harvesting trees on private land. It is not known to what degree potential erosion and flooding from this harvesting will alter the immediate and adjoining ecosystems, nor is the impact of downslope or downstream users on economic opportunities known.

Climate change in the Prairies and Boreal Plains ecozones

The Prairies ecozone has a highly variable climate and experiences large daily and extremely large annual ranges in temperature; ranges of 75°C are not uncommon within a single year. Precipitation trends are not as obvious. Winter snowfall contributes about 30% of the annual precipitation. Summer precipitation is typically showery in character and thus shows significant variability. Also, wide fluctuations in precipitation between decades have been observed over the period of record: the drought of the 1930s, the wet spells of the early 1950s, the severe isolated drought of 1961, and the droughts of the 1980s. Past studies have shown that warmer temperatures in the Prairies ecozone correlate with lower effective precipitation and higher evaporation. Thus, the sensitive semiarid and subhumid climate of the Prairies ecozone can be particularly prone to climate change.

The Earth's climate has warmed about 0.5°C in the last century (see Chapter 15). It is not clear how much of this warming is due to increasing concentrations of greenhouse gases, from both natural and human causes, or to the Earth's natural cycle of variability. Temperature increases in the grassland area of the Prairies ecozone over the last 100 years have exceeded this rise, with the average temperature increasing 0.9°C. A more distinct upward trend has taken place over the past 15 years. Research shows that the overall warming trend is within the bounds of the natural climatic variation experienced in preindustrial times. Should it continue, however, these bounds will soon be exceeded, possibly leading to a period of climate change unlike any that has occurred in the last several hundred thousand years (Hengeveld 1995).

Average seasonal temperatures for the decade 1980–1989, compared with the period 1951–1980, show a substantial warming trend in winter, spring, and fall. The frequency of extremely low minimum temperatures in the winter season also points to a warming trend. Temperatures of –40°C or lower could be expected in the

Box 4.10
Wind farming on the Prairies

The potential for economical production of electricity from wind generators is high in parts of the Prairie grasslands. As the cost of equipment decreases, the efficiency and reliability of the generators increase, and utilities become more comfortable with this form of electrical generation. By entering into purchasing agreements with wind farmers, utilities could significantly decrease their carbon dioxide emissions.

The Cowley Ridge Wind Plant in southern Alberta became fully operational in 1994. Its electricity will be purchased by TransAlta Utilities, which relies heavily on the burning of fossil fuels to produce electricity. The company expects the wind-generated electricity to reduce annual emissions of carbon dioxide by 46 000 t, of sulphur dioxide by 125 000 t, and of nitrogen oxides by 77 000 t. These numbers appear large but in fact represent less than 1% of the annual Alberta emissions of these substances.

A report called Wind resources assessment in southwestern Saskatchewan *was completed in 1994, as part of a study jointly funded by Natural Resources Canada and SaskPower. The study demonstrated that there is a significant potential to create energy from the wind resource in parts of southwestern Saskatchewan.*

Prairies ecozone at least twice every winter in the early 1900s. Now, a temperature of –40°C occurs only once every four winters on average (Herrington 1995). The data indicate no significant differences during the summer (Hengeveld 1995).

Within these averages, there has also been increased climatic variability, such as the extremes of heat and cold that were experienced with unusual frequency in the last decade. Temperatures during the summers of 1992 and 1993 did not follow the warming pattern, probably because of the cooling effects of the volcanic ash injected into the atmosphere during the eruption of Mount Pinatubo, in the Philippines, in June 1991. The grasslands were cooler and cloudier during these years, and the summer of 1993 was unusually wet. Most regional economic activities were affected, particularly agriculture: plant maturation slowed, drying conditions were poor, and access to fields was restricted because of saturated soil conditions.

Human activities are adding large quantities of greenhouse gases to the atmosphere, particularly carbon dioxide, released when fossil fuels are used for transportation and to generate electricity (Box 4.10 shows some innovative alternatives to using fossil fuels). Carbon dioxide was also released to the atmosphere from prairie soils during the early stages of their cultivation. Chemical fertilizers used on the grasslands are thought to be a source of nitrous oxide, another greenhouse gas. Finally, the release of methane by livestock and in natural gas processing is also contributing to greenhouse gas emissions.

Computer simulations of the global climate over the next 50 years, based partly on the assumption that carbon dioxide concentrations in the atmosphere will double, consistently forecast warmer temperatures. Most computer models predict global warming in the range of 1.5–4.5°C, predominantly in the winter season. Results from the Canadian Climate Centre General Circulation Model indicate a probable 5–7°C rise in annual surface temperature for the Prairie provinces (Saunders and Byrne 1994). There is little consistency among these same models in predicting future precipitation trends. Some models predict higher seasonal precipitation, whereas others predict lower values. Most models forecast a decrease in soil moisture, even with higher annual precipitation, because of increased annual evaporation.

Climate change could have profound implications for the Prairies and Boreal Plains ecozones. Warmer temperatures, without a change in winter snowfall, would tend to reduce the winter snowpack and change the timing of spring thaw. The resulting reduction in runoff would increase the frequency and duration of shortages in domestic water supplies, as well as the water available for industrial and agricultural uses, such as hydro generation and irrigation. In addition, less snow cover could significantly reduce snow-related winter recreational activities in the southern Prairies ecozone (Wheaton 1994). As quantity falls, the quality of surface water could suffer as well.

A warmer climate would have both positive and negative impacts on agriculture. In Alberta and Saskatchewan, increased temperatures would result in about a 50% increase in growing season heat energy in most areas (McGinn et al. 1995). As a result, the potential for cultivating higher-yield crops requiring a longer and warmer growing season could increase. Grain corn could become an important agricultural crop in Manitoba, and winter wheat would do well. Yet this warming trend would also exacerbate pest infestation and loss of soil moisture to evaporation, impeding any agricultural gains (Hengeveld 1995). Evaporation would take place over a longer seasonal period, leading to an increase in the frequency and severity of droughts (Williams et al. 1988). Persistent years of low precipitation might cause ponds to dry up permanently, with repercussions for waterfowl and other wetland species. The Prairies ecozone could expand northward into the existing parkland and boreal forest ecoclimatic area (Rizzo and Wiken 1992). However, much of this land consists of marginal soils that are unsuitable for cereal grain production.

A warmer climate would also have implications for forests. In the transition zone, the frequency of droughts would cause the demise of the aspen bluffs. In the past, aspen has adapted to periodic droughts that kill the above-surface parts of the tree but leave the roots alive. If droughts became more frequent, however, regeneration could fail entirely. The warmer and drier climate could also prevent the existing trees of the Boreal Plains ecozone from regenerating. Increased frequency and severity of fires might contribute to this phenomenon, as established coniferous trees perished and seedling reproduction failed owing to the drier climate. In the

northern reaches of the ecozone, the longer growing season could enhance the growth of forests, provided precipitation increased along with temperature. As well, the boreal forests might expand northward into the present sub-Arctic taiga.

State of the Environment and Sustainability: Society's Response

Environmental management programs on the Central Plains, as in other areas of Canada, have tended to focus on resource types (e.g., fisheries, wildlife, soils) or upon specific industry sectors (e.g., agriculture, forestry, mining). This traditional sectoral approach has been applied in most resource and environmental management programs. Within the context of sustainable development, the emerging response is to deal with environmental and development issues in an integrated way, looking at all sectors that share a common resource. Resource management is carried out from an ecosystem perspective, recognizing the interdependencies among all elements in an ecosystem.

This approach is part of a broad international trend towards integration of economic and environmental goals, following the philosophy of the Brundtland Commission report, which recognized that a healthy environment and a sustainable economy are interdependent and that both are necessary to achieve sustainable development. Through its contribution to new initiatives in environmental policy and programming, the report assisted in building the conceptual framework of a sustainable economy. The following section describes the development of this approach in the Prairies and Boreal Plains ecozones and its implementation in recent years in the major sectors discussed in this chapter.

After sponsoring the Canadian hearings of the Brundtland Commission, the Canadian Council of Ministers of the Environment established the National Task Force on Environment and Economy (NTFEE) in 1986. The NTFEE report became a blueprint for Canadian follow-up action to the Brundtland Commission's report, calling for the development of sustainable development strategies at the national and provincial/territorial levels. In particular, the NTFEE recommended the establishment of round tables to provide a forum at which decision-makers from many sectors could discuss policy issues related to the implementation of sustainable development.

All three Prairie provinces undertook initiatives to implement the recommendations of the task force. Manitoba established its round table in 1989 under the chairmanship of the premier. It remains the only round table in Canada to be chaired by a first minister. In 1994, the Manitoba Round Table released a proposal to develop a Sustainable Development Act for Manitoba. Saskatchewan and Alberta established round tables in 1989 and 1990, respectively. The Saskatchewan Round Table was given a mandate to develop a conservation strategy; it was disbanded in 1992 following the completion of the strategy. The Alberta Round Table developed a vision of sustainable development and supporting principles and indicators to monitor Alberta's progress towards sustainable development, completing its mandate in 1993.

Although there are some variations, the main principles embodied in the sustainable development strategies are comparable across the three Prairie provinces. The common links include achieving environmental and economic integration, conserving biological diversity, and maintaining essential ecological processes and overall environmental quality (Table 4.8).

By the early 1990s, sustainability had become a central theme in the delivery of the federal government's Green Plan. The Green Plan emphasized a federal commitment to provide scientific and program support to enhance Canada's ability to make environmentally responsible decisions. Green Plan programs, delivered by a number of federal agencies in partnership with the provinces/territories, industry, and the public, emphasize science, citizenship, and integrated approaches to resolve environmental issues.

Sustainable development strategies at the national and provincial/territorial levels are now reflected in the programs and policies of all industry sectors and government departments. In the Prairies and Boreal Plains ecozones, this approach is beginning to have a significant effect on how activities such as agriculture and forestry — which have a major influence on the environment — are undertaken.

In the early 1990s, the Sustainable Agriculture Component of the Green Plan replaced the National Soil Conservation Program as the cornerstone of federal environmental programming in agriculture. Implemented through cost-shared agreements with the provinces, the component addresses a range of environmental issues related to agriculture, including soil conservation, water quality, and preservation of wildlife habitat. Each province established its own priorities and, in conjunction with special interest groups, developed programs to deal with these issues in an integrated manner.

Such programs have encouraged producers to adopt practices that enhance the sustainability of their farms' natural resources, by planting shelterbelts, creating grassed waterways, and practising conservation tillage. Under the Permanent Cover Program, more than half a million hectares of marginal land have been converted from annual crop production to permanent cover.

Opportunities for wildlife and biodiversity conservation have increased as producers realize that wild species can be accommodated within current farming practices. The NAWMP is largely responsible for recognition among farmers of the need to restore wetlands and adjoining waterfowl habitat. Initiatives under the Prairie Habitat Joint Venture have included restoring grasslands near wetlands, improving pasture management, converting marginal annual cropland to hay or pasture, and delaying haying until after the nesting season. These practices preserve soil and water quality, a benefit to agriculture, while maintaining and enhancing wildlife habitats.

The ecosystem approach has also been extended to management of pesticides (herbicides and insecticides) that are used in agriculture, and a practice that can sig-

Table 4.8
Sustainable development principles adopted by the Prairie provinces

Theme	Manitoba	Saskatchewan	Alberta
Conservation, preservation, and biodiversity	Maintain essential ecological processes, biological diversity, and life support systems of the environment; harvest renewable resources on a sustained yield basis; and make wise and efficient use of renewable and nonrenewable resources.	The preservation of biological diversity and wise use of nonrenewable resources are not identified as principles but are goals of Saskatchewan's Environmental Agenda.	Alberta's biological diversity is preserved. Albertans live within the province's natural carrying capacity.
Integration	Ensure that economic decisions adequately reflect environmental impacts, including human health. Environmental initiatives will adequately take into account economic impacts and support decision-making and planning processes that are open, are cross-sectoral, and incorporate long-term time horizons.	The environment cannot be dealt with in isolation, but must be protected, managed, and fully integrated into all aspects of the economy and society.	The economy is healthy. The economy is diversified, resilient, globally competitive, and environmentally responsible.
Prevention	Anticipate, prevent, or mitigate significant adverse environmental (including human health) and economic impacts of policy, programs, and decisions.	Better to "anticipate and prevent" environmental damage, rather than "react and cure" after the fact.	Strengthen anticipation, prevention, and mitigation of activities that challenge Alberta's commitment to sustainable development.
Stewardship	Manage the environment and economy for the benefits of present and future generations.	Resource conservation is a long-term investment, recognizing the needs of future generations.	Albertans are stewards of the environment and the economy.
Global responsibility	Recognize that there are no boundaries to our environment and that there is ecological interdependence among provinces and nations.	Meeting global responsibilities is not a principle but is one of the goals of Saskatchewan's Environmental Agenda.	Albertans are responsible global citizens.
Shared responsibility	All Manitobans acknowledge responsibility for sustaining the environment and economy, with each being accountable for decisions and actions in a spirit of partnership and open cooperation.	Cooperative approaches among all sectors will foster a smoother transition towards sustainability.	Shared responsibility for protection of the environment while maintaining economic growth.
Full (environmental) cost accounting	Encourage development and application of systems for resource pricing, demand management, and incentives to encourage efficient use of resources and full environmental costing of decisions and development.	Information on environmental cost should be available to guide marketplace decision-making, such that these costs are recognized and incorporated into the price system.	Market forces and regulatory systems work for sustainable development. Move full-cost accounting from theory into practice. Implement natural resource accounting.
Waste minimization	Endeavour to reduce, reuse, recycle, and recover the products of our society.	Integrate waste management strategy to meet CCME[a] targets for reduction	
Environmental enhancement	Enhance the long-term productivity, capability, quality, and capacity of our natural ecosystems.		
Rehabilitation and reclamation	Endeavour to restore damaged or degraded environments to beneficial uses.	Mine reclamation policy allows a "cradle-to-grave" approach.	
Scientific and technological innovation	Research, develop, test, and implement technologies essential to further environmental quality.		Develop environmental technology and expertise to meet the needs of the future.
Precautionary approach		Faced with uncertainty about environmental impact, it is preferable to take precautionary measures to maintain the status quo.	Expand the application of the environmental precautionary approach.
Ecosystem approach		Recognize that all components in an ecosystem are closely linked and cannot be managed in isolation from one another.	
Healthy environment and quality of life		Support the development of community environmental strategies; government and community groups must promote community self-reliance, interdependence, and environmentally friendly ways of living.	Urban and rural communities offer a healthy environment for living.
Environmental education	Public requires access to adequate information to make responsible decisions for sustainable development.	Successful transition to sustainable development depends upon an informed and educated society; many players have a role, including governments, industry, educational institutions, and nongovernmental organizations.	Albertans are educated and informed about the economy and the environment (workplace and education system).

[a] CCME = Canadian Council of Ministers of the Environment.
Source: Bjonback (1995).

nificantly affect soil biota, water quality, and human health. Contamination of surface water and groundwater may harm fisheries, wildlife, irrigated agricultural crops, and water for industrial use and drinking. Insecticides are used on 5% of cultivated land in Alberta and Saskatchewan and on about 12% in Manitoba. The agricultural component of the Green Plan has addressed pesticide and pest management programs in the Prairie provinces. Most of these projects encourage an integrated approach to pest management, including more efficient application of pesticides.

Similarly, in the forestry sector, a number of significant international and national environmental strategies were completed. In Canada, under the auspices of the Canadian Council of Forest Ministers, a national strategy for sustainable forest management was developed. The federal and provincial governments adopted the new strategy by signing the Canada Forest Accord in 1992. It includes a number of steps to enhance forest ecosystem management and maintain biological diversity (Canadian Council of Forest Ministers 1992b). Public interest in the environmental impacts of forestry centres on the extent of land clearing, implications for water quality and recreation, and, most recently, biodiversity.

The Canadian Biodiversity Strategy was endorsed by the federal government in April 1995 and subsequently by all provincial and territorial governments. The strategy was devised to implement the United Nations Framework Convention on Biological Diversity, which was signed by Canada and several other nations at the 1992 United Nations Conference on Environment and Development in Brazil.

Each of the Prairie provinces has initiated sustainable forest management strategies. In consultation with a wide range of industrial, cultural, environmental, and academic groups, the Alberta government is developing the Alberta Forest Conservation Strategy (1994). Its goal is to maintain and enhance the long-term health of forest ecosystems for the benefit of all living things, while providing environmental, economic, social, and cultural opportunities (Alberta Environmental Protection 1994). Following its own provincial strategy, Saskatchewan is developing several new programs in integrated forest management. These include new forest management licence agreements to regulate the harvest of timber resources, forest renewal programs, and a protected area policy. Manitoba has developed an Integrated Forest Management Plan, which will build on a plan initiated in 1981. Its many objectives include encouraging and enforcing forest uses that are sound from an ecosystem perspective and allocating forest resources in a way that is consistent with sustainable development. Meanwhile, the federally sponsored program by which local user groups have formed nonprofit corporations to oversee forest management in the area emphasizes integrating environmental aspects, such as wildlife habitat and overall biodiversity, directly into improved forest management practices. Provincial forest agencies are partners, as provincial forestland is included in the model forest areas.

Strategies are also being developed to safeguard ecosystems and species. Alberta has pledged to complete a protected area network by the year 2000, which will include the full range of natural landscapes and unique environmental diversity. Saskatchewan is preparing a protected area strategy for public consultation, with the intention of completing a comprehensive system of protected areas that will maintain the province's biodiversity and cultural heritage. An Action Plan for a Network of Special Places for Manitoba was released in March 1994. It attempts to identify all types of natural areas, including small parcels of tallgrass prairie, wilderness parks, wildlife management areas, provincial forests, and ecological reserves.

Alberta is also in the early stages of developing a conservation data centre to collect and disseminate information critical to the conservation of the province's biodiversity. The Saskatchewan Conservation Data Centre, completed in 1992, is now operational, collecting, interpreting, and disseminating information critical to biodiversity conservation. Much of its research has focused on the status and distribution of threatened and endangered species, natural ecological communities, and protected areas. The Manitoba Conservation Data Centre, meanwhile, is working to establish a comprehensive inventory of plant and animal species and representative natural communities.

Water quality and quantity issues are critical to every aspect of economic and environmental sustainability in the Central Plains. For example, recent federal–provincial agricultural sustainability agreements include water quality as a key component of sustainable agriculture. In recent years, water management initiatives have been delivered within a broader and integrated context with respect to ecosystem planning and regional development. In 1992, the federal government and the three Prairie provinces amended the Master Agreement on Water Apportionment to include a water quality agreement. It directs the Prairie Provinces Water Board, which administers the agreement, to promote a preventative and proactive ecosystem approach to interprovincial water quality management. The agreement also sets water quality objectives for interprovincial rivers and commits each signatory to take reasonable and practical measures to maintain or improve existing water quality.

While preparing a Land and Water Strategy in 1989, Manitoba developed a set of water policies covering water quality, supply, use, conservation, and allocation, as well as flooding, drainage, and public education. The province's current management approach recognizes water as both an economic and environmental resource — one that must support not only human needs but also life-sustaining ecosystems. To help deliver and support an integrated approach to resource management, the province created regional offices to respond to local concerns.

The Saskatchewan Water Corporation was created in 1984. It was designed to reflect the growing need for a more integrated approach to water management and to include social, economic, and environmental considerations in management deci-

sions. The corporation is responsible for a range of functions, from water supply operations and planning to water licensing and administration. Recently, the corporation launched initiatives to develop integrated water management and protection strategies for key river basin regions. The Saskatchewan Wetland Conservation Corporation, established to coordinate the implementation of the NAWMP in Saskatchewan, coordinated a recently developed wetland policy for the province, which was approved in 1995.

In 1993–1994, water management in Alberta was consolidated under the Alberta government's new Department of Environmental Protection. The province has actively solicited public input and participation in policy reviews and examination of water use issues. For example, the Bow River Water Quality Council, which reports directly to the department, includes all interests sharing the resource, including municipal, agricultural, and Aboriginal representatives. The council employs government experts to conduct basin-wide assessments of the long-term health of the river basin's water resources. The province is currently reviewing and updating its water management strategy from a sustainable development perspective. In the early 1980s, it gave interim approval to a wetland policy developed by its Water Resource Commission for settled areas. A wetland policy for forested areas has since been completed, and a combined wetland and forestry policy is awaiting government approval.

These initiatives are examples of the integrated, cross-sectoral approach now being taken in environmental management across the Central Plains. Each one acknowledges the impacts of natural or human-induced stresses on any given resource, and each reflects a number of common themes. For instance, they recognize that an ecosystem approach respects the reality of shared use by all sectors of the economy and society, that management needs to become more decentralized, and that the public needs to be involved in decision-making at the local level. Economic behaviour has become more closely linked to ecological principles through incentives, education, and conservation measures. In sum, environmental values and recognition of the economic value of a healthy environment are being incorporated into decision-making in homes, farms, businesses, and institutions throughout the Central Plains.

Outlook: State of the Environment and Sustainability

Sustainable development has considerable staying power as a focal point for environmental, economic, and social policies in the 1990s and beyond (Bjonback 1995). The concept reflects a global political constituency that spans environmental groups, traditional conservation movements, business, and governments alike. It has gained international legitimacy among scientists and resource management experts. Perhaps most importantly, it embodies public concern for the evolving environmental condition of the planet and its ability to support future generations. Sustainable development has been embraced by the federal government and by all three Prairie provinces and is gradually taking hold as the basis for government policies and programs. Examples of this shift have been presented throughout this chapter and are summarized in Table 4.9.

Determining progress towards sustainable development is difficult, however, without criteria against which it can be judged. The goals set out in the 1980 World Conservation Strategy (IUCN et al. 1980) provide an internationally recognized framework for ecological sustainability. These goals were adopted as a framework because they provide a well-accepted and well-articulated set of ecological guidelines that succinctly address all the main anthropogenic environmental stresses, and they constitute a short but comprehensive checklist against which we can evaluate how well human activities stay within these ecological guidelines. Specifically, the goals are to maintain essential ecological processes and life support systems, to preserve biological and genetic diversity, and to ensure the sustainable use of species and ecosystems.

As shown in Table 4.9, some progress has been made in the Prairies and Boreal Plains ecozones towards achieving these goals. A strong soil base is a core life-supporting component of any ecosystem, as the bulk of all food production depends on it. In recent years, farmers have learned the benefits of conservation tillage and leaving less land to summerfallow. Crop varieties have increased significantly, contributing to greater biodiversity and ecosystem health. Restoration efforts have seen more than half a million hectares of cultivated land return to permanent cover, with corresponding reductions in soil degradation.

Forests are another critical life support system, influencing climate and providing watersheds that ensure a continuous flow of clean water and protected soil cover (IUCN et al. 1980). The 1992 National Forest Strategy, *Sustainable forests — a Canadian commitment*, encourages managing forests as ecosystems, with the overall goal being to ensure the sustainable use and conservation of Canada's forests. Traditional tree crop production is being replaced with sustainable ecosystem development. Forest managers are beginning to recognize trees as essential components in an interdependent ecosystem. Better forest management includes making clear-cut areas smaller to minimize fragmentation of wildlife habitat, including that essential to migratory birds.

Preserving biodiversity, the second World Conservation Strategy benchmark, is critical to sustaining and improving agriculture, forestry, and fisheries production. Biodiversity is the raw material for much scientific and industrial innovation. It is impossible to predict what species may become of use or how, or which ones are vital parts of life support systems on which people depend. Humankind is obliged, to its descendants and to other species, to act prudently (IUCN et al. 1980).

A central component of species survival is habitat preservation. In the Central Plains, loss of species habitat due to conversion of

Table 4.9
Environmental policy/programming trends

Old approach (to mid-1980s)	New approach (mid-1980s and beyond)	Examples of new approach
Sectoral environmental management (e.g., water, soils, air, biota)	Integrated management	• Manitoba's Land and Water Strategy • Agriculture sustainability agreements • Alberta's Natural Resource Management Policy Framework • Saskatchewan's Sustainability Management Policy
Public consultation and input as part of program delivery by government	Public participation and direct role in program planning, development, project priority-setting program, and, in some cases, program delivery	• Northern River Basins Study • Development of the *Alberta Environmental Protection and Enhancement Act* • Alberta's review of water policy and legislation • Provincial wetlands policies
Regulation setting/penalties for waste disposal	Cooperative institutions, partnerships, educational programs, voluntary approaches, and economic instruments	• Environmental codes of practice developed by the mining industry • Government/industry waste reduction targets • Recycling, deposit refund systems • Saskatchewan Waste Management Strategy
Technological "fix" of specific environmental issues or hazards	Ecosystem adaptation/accommodation	• Research into biological control of pests
Species-specific protection, sustained yield of renewable resources	Ecosystem balance, biodiversity, sustained use of ecosystem, integrated resource management	• National and provincial forest management strategies • Prairie Conservation Action Plan • Provincial and multijurisdictional protected area networks • Provincial conservation data centres
Environmental concerns are constraints to economic development	Environmentally sustainable development	• National and provincial sustainable development strategies • Agriculture Canada policy reform (four pillars)
Centralized administration and planning	Decentralized administration and planning	• Creation of regional offices, provincial environmental and natural resource agencies
"End-of-pipe" solutions: react to environmental issues and cure with cleanup and remediation programs	Anticipate and prevent problems and issues before they occur, precautionary principle, pollution prevention	• New *Manitoba Mines and Minerals Act* requires restoration strategies and evidence of financial security for decommissioning • *Canadian Environmental Protection Act* requires assurance of environmental safety of new products by manufacturers prior to introduction • Pollution prevention strategies and environmental awareness programs of provinces and federal government
Water development and management on a sectoral basis	Water part of ecosystem management and economic development strategies, utilize demand management and conservation	• Saskatchewan's integrated water management strategies approach • Alberta's proposed Water Act • Manitoba's Land and Water Strategy
Environmental objective-setting by technical experts from government	Governments support and facilitate development of objectives by public, industry, and interest groups	• Provincial and national sustainable development strategies • Manitoba's Regional Round Tables process
Single agency delivery of environmental programs; separation from "economic" programs	Partnerships, especially among economic and environmental interests	• Prairie Habitat Joint Venture • Bow River Water Quality Council • International Institute for Sustainable Development — Evaluative Framework

Source: Bjonback (1995).

land to other uses has been considerable. The NAWMP is a landmark habitat restoration effort, resulting in the restoration of hundreds of thousands of hectares of wildlife habitat across the Central Plains. Landowners and concerned agencies have launched several projects to reinvigorate critical shoreline habitat. These limit soil erosion, remove residues from water, and reduce flooding. The conservation data centres of the three Prairie provinces are identifying all types of natural areas and native species, a critical step on the road to their preservation. Through joint initiatives coordinated by the Canadian Wildlife Service, recovery teams are working to bring back individual species whose population levels have become critically low.

Success in meeting the objectives set out by the World Conservation Strategy requires that the principles of sustainable development be built into projects of both the public and private sectors (Bjonback 1995). In the Central Plains, almost every new environmental initiative and many new economic initiatives make reference to sustainable development. Manitoba has probably taken the boldest step by developing the outline for a Sustainable Development Act. The Alberta Round Table on Environment and Economy has devised 59 indicators for measuring progress towards sustainable development. Saskatchewan's Environmental Agenda has set the preservation of biological diversity and wise use of nonrenewable resources as primary goals. Meanwhile, Environment Canada's Prairie and Northern Region is developing ecozone plans aimed at ensuring that its programs and activities contribute to the health and integrity of regional ecozones.

Further advances will require greater public understanding and acceptance of the benefits to be derived from integrated environmental and economic decision-making. How quickly society adapts to the new ecosystem approach and how well governments, industry, and other components of society move to implement sustainable development principles will determine the future potential for ecosystem integrity and biodiversity in the Central Plains.

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Chapter 5 Boreal Shield Ecozone

Highlights

The Boreal Shield ecozone stretches 3 800 km from the east coast of Newfoundland to northern Alberta and is the largest of Canada's 15 terrestrial ecozones. It covers over 1.8 million square kilometres and encompasses almost 20% of Canada's land mass. Its rivers and lakes account for 22% of Canada's freshwater surface area.

■

Many lakes and shallow soils in the Boreal Shield ecozone are extremely sensitive to acidic precipitation. Acidic precipitation from both local and distant sources may have weakened the general vigour and growth rate of trees in sensitive areas. Reductions in inputs of acidic materials to the atmosphere have been legislated and are being implemented. Nevertheless, a substantial portion of this ecozone continues to receive elevated levels of acidic deposition.

■

The 106 million hectares of timber-productive forestland make up close to half of Canada's total. Since the 1920s, the total area harvested annually has doubled to approximately 400 000 ha. About 90% of all harvesting is carried out through clear-cutting.

■

Recent advances in forest management include a dramatic drop in the application of chemical insecticides; improved regulations controlling the release of toxins from pulp mills; a move towards more ecosystem-based forest inventories; the adoption of integrated forest management plans; and the expansion of environmental monitoring sites in the boreal forest.

■

Mining provides the economic mainstay for more than 80 communities in the Boreal Shield ecozone. Production is estimated at over $6 billion annually.

■

Mining may affect downstream air and water quality. Adverse impacts have significantly lessened over the past decade owing to innovations on several fronts: new regulatory and policy instruments, improved pollution prevention and control technologies, more comprehensive provisions for mine decommissioning, and strengthened environmental commitments made by the mining industry.

■

Thirty-nine percent of Canada's hydroelectric capacity is located on rivers arising in or flowing through the Boreal Shield ecozone. Of Canada's 662 large dams, 279, or 42%, are located here. The long-term maintenance and reclamation of aging dams are emerging environmental concerns that have yet to receive significant attention from provincial governments.

■

Although much of the hydroelectric development in this ecozone has already been completed, ongoing initiatives, such as regulated streamflows and community-based project planning to mitigate impacts from dams, demonstrate promising commitments to environmental protection.

■

Several provinces are showing a renewed interest in creating new protected areas and better managing existing ones. Six new provincial parks are proposed in Quebec's Provincial Parks Action Plan (1992–1997): Rivière Vauréal, Mont Valin, Monts Otish, Lac Albanel et Rivière Temiscamie, Aguanus-Kenamu morainic complex, and Harrington Harbour. Manitoba opened Amisk Provincial Park in 1995, and Ontario is committed to expanding Wabakimi Provincial Park to almost 900 000 ha.

■

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Studded with evergreens, the granitoid rocks of the Boreal Shield ecozone stretch 3 800 km from the east coast of Newfoundland to northern Alberta (Fig. 5.1a). This rugged, rolling landscape of bedrock and forests is situated at the geographical overlap of two of the biggest physiographic areas on Earth: the Canadian Shield and the boreal forest. The largest of Canada's 15 terrestrial ecozones, the Boreal Shield ecozone includes parts of six provinces, covers over 1.8 million square kilometres, and encompasses almost 20% of Canada's land mass. Its rivers and lakes account for 22% of the country's freshwater surface area. Rivers that have their headwaters in the Boreal Shield ecozone include the Saguenay, Albany, and Moose rivers. Huge bodies of fresh water, such as lakes Winnipeg, Superior, and Huron, lie along its borders. Within it are countless other lakes, some big, such as Lake Nipigon and Lac Saint-Jean, and others too small to be named.

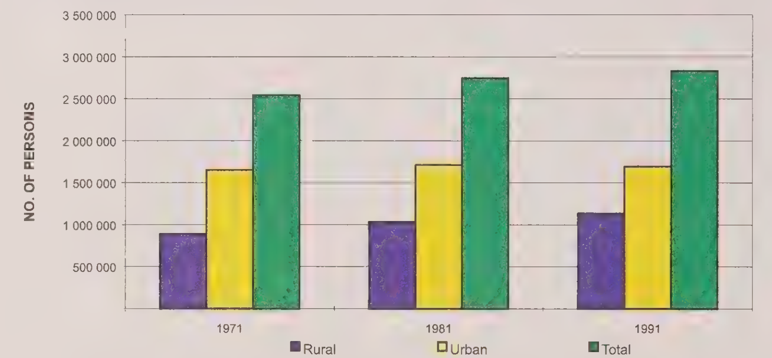
The original peoples of this land — the Beothuk, Algonquians, Athapaskan, and Iroquoian — through their relatively small numbers and subsistence hunting and gathering lifestyle, lived within nature's cycles and the movements of the animals and fish on which they depended. By the 1600s and 1700s, the area's rich fur, timber, and mineral resources had already attracted significant interest from European visitors. Today, some 200 years later, other resources, plus rich hydroelectric potential, have been added to the backbone of the Boreal Shield ecozone's economy.

This chapter begins with an overview of the main ecological and socioeconomic features of the ecozone. The following sections focus in turn on the three most significant environmental stresses affecting the ecozone: forestry, mining, and hydroelectric development. They describe these stresses, interpret their significance, and report on actions to mitigate their impacts. The chapter concludes with an assessment of progress made towards sustainable development in the Boreal Shield ecozone.

Figure 5.1a
Extent of the Boreal Shield ecozone

Source: State of the Environment Directorate, Environment Canada.

Figure 5.1b
Population trends, 1971–1991



Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada. For further details, see Endnotes.

Key Ecological and Socioeconomic Features

Ecological setting

Although the core character of the Boreal Shield ecozone is quite distinct, the ecozone displays a wide range of ecological diversity. Its terrestrial and aquatic ecosystems are dominated by the continental climatic regime, but some show the influence of the zone's extensive coastal periphery and the marked variations in soils and bedrock exposures.

Climate

The climate of this ecozone is generally continental, with long, cold winters and short, warm summers (Fig. 5.1f). Generally, there is an eastward increase in precipitation, from 400 mm annually in the west to in excess of 1 000 mm in the east. The higher precipitation in the east is due to the greater frequency of storms, which bring warm, moist, maritime tropical air originating in the Gulf of Mexico. The average temperature in January is –15°C, whereas in July it is 17°C. The average annual number of frost-free days ranges

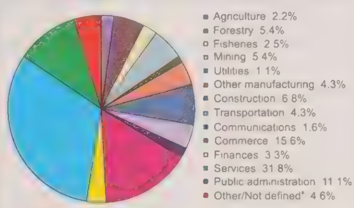
Figure 5.1c
Population changes in selected centres, 1971–1991

Selected centres	Population		
	1971	1991	% change
Flin Flon, Man.	8 873	7 119	-20
Thompson, Man.	1 407	14 977	964
Thunder Bay, Ont.	112 093	124 427	11
Sault Ste. Marie, Ont.	80 332	81 476	1
Kapuskasing, Ont.	12 834	10 344	-19
North Bay, Ont.	49 187	55 405	13
Amos, Que.	2 087	13 783	560
La Tuque, Que.	13 099	10 003	-24
Sept-Îles, Que.	24 320	24 848	2
Corner Brook, Nfld.	26 309	22 410	-15
St. John's, Nfld.	131 814	171 859	30

Note: The geographic extent of a Census Metropolitan Area in 1971 may not correspond to that for 1991. For further details, see Endnotes.

Source: Special tabulations prepared by Statistics Canada. For further details, see Endnotes.

Figure 5.1d
Labour force composition, 1991



Total labour force: 1 358 020

Note: Using the 1970 Standard Industrial Classification, the four primary sectors have been grouped with their respective first-stage resource processing industries. For further details, see Endnotes.

* "Other/Not defined" represents labour force categories that were less than 0.5% of the total labour force as well as responses for which the respondent did not specify the industrial category in which he/she or other household members were employed.

Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada.

between 60 and 100, with some locations having fewer than 40. This limits agriculture in the Boreal Shield ecozone, as grain and many other crops need at least 100 frost-free days in order to grow. Boreal Shield ecozone regions bordering the Great Lakes and the Atlantic Ocean have longer growing seasons, as temperatures are moderated by the presence of large water bodies (Environment Canada 1982, 1993; Wiken 1986).

Geology and soils

The bedrock of much of the Boreal Shield ecozone is granitoid gneiss and plutonic rock formed between 2.7 and 1.0 billion years ago. Many of the minerals that contribute to the ecozone's economy were formed during these geological times. Uplift and erosion then occurred intermittently over much of the area until about 1 billion years ago, when most geologic activity ceased.

During the last ice age, which ended some 10 000 years ago, the Boreal Shield ecozone was repeatedly scoured by advancing glaciers. While in retreat, they blanketed much of the landscape with coarse moraines released by melting ice. The natural depressions in the Canadian Shield as well as the many poorly drained depressions left behind by the glaciation now form the millions of lakes, ponds, and wetlands that give this ecozone its distinctive character.

The glaciers also scraped away much of the preglacial soil cover. Today, not only are most soils relatively thin, but they are also highly acidic and low in nutrients and oxygen.

Vegetation

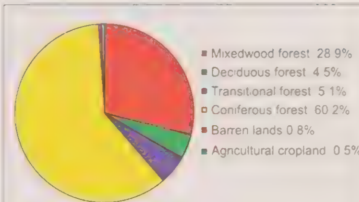
Cool temperatures, a short growing season, frequent forest fires, exposed bedrock, and often shallow acidic soils are among the many challenges faced by plant life in this ecozone. However, certain coniferous trees have adapted well to the Boreal Shield ecozone, as shown by the vast evergreen forests that blanket much of this ecozone. Almost 70% of the ecozone is considered productive for timber.

The forest is dominated by a few highly adaptable tree species, such as Black Spruce, White Spruce, Jack Pine, and Balsam Fir. Black Spruce, the most common species, yields high-quality wood pulp and is therefore a prime species for Canada's large paper industry.

The south of the ecozone shows a wider distribution of broad-leaved trees, such as White Birch, Trembling Aspen, and Balsam Poplar, and other conifers, such as White, Red, and Jack pine. In southeastern parts of the ecozone, species characteristic of more temperate climates are common, including the Yellow Birch, Sugar Maple, Black Ash, and Eastern White Cedar (Fig. 5.2).

Throughout the Boreal Shield ecozone, the forests are mixed with innumerable bogs, fens, marshes, and other wetlands. Covering nearly 20% of the ecozone,

Figure 5.1e
Land cover distribution



Total land area
1 674 308 km²

Note: For the definitions of surface cover types, see legend to Figure 10.11, Chapter 10.

Source: National Oceanic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR) imagery; Manitoba Remote Sensing Centre, Manitoba Department of Natural Resources.

Figure 5.1f

Air temperature, degree-days, and precipitation in selected centres

Selected centres	Air temperature (°C)				Degree-days[a]		Precipitation			
	Mean January maximum	Mean January minimum	Mean July maximum	Mean July minimum	Heating (<18°C)	Growing (>5°C)	Mean annual rainfall (mm)	Mean annual snowfall (cm)	Mean total precipitation (mm)	Days with measurable precipitation
Cree Lake, Sask.	−17.3	−28.9	21.2	10.3	7 479	1 106	313	180	451	144
Flin Flon, Man.	−16.8	−26.7	23.2	12.4	6 809	1 379	345	144	484	132
Thompson, Man.	−19.5	−30.6	22.6	8.8	7 824	1 038	352	201	536	146
Thunder Bay, Ont.	−8.9	−21.3	24.4	11.0	5 749	1 427	547	196	704	138
Sault Ste. Marie, Ont.	−5.5	−15.4	24.3	11.2	5 097	1 586	633	316	906	173
Kapuskasing, Ont.	−12.3	−24.9	23.7	10.2	6 454	1 336	558	326	861	190
North Bay, Ont.	−8.1	−18.0	23.8	13.2	5 363	1 648	736	268	974	176
Amos, Que.	−11.8	−22.9	23.1	11.0	6 250	1 366	678	244	920	154
La Tuque, Que.	−8.3	−20.4	25.5	12.3	5 396	1 692	695	238	933	161
Sept-Îles, Que.	−9.3	−20.1	19.6	10.8	6 229	1 005	729	415	1 128	166
Corner Brook, Nfld.	−2.1	−8.9	21.9	12.8	4 737	1 432	771	414	1 186	201
St. John's, Nfld.	−0.7	−7.9	20.2	10.5	4 865	1 209	1 163	322	1 482	217

Note: Data based on 1961–1990 climatic normals.

[a] A unit of measurement of the deviation of the mean daily air temperature from a predetermined standard (at a particular location). For further details, see definition of degree-days in Glossary.

Source: Environment Canada (1994).

Table 5.1

Number of bird species occurring in the Canadian boreal region

Overwintering locations	No. of species		
	Breeding in boreal region	Breeding north of the boreal region	Total
Within the boreal region	35	10	45
South of the boreal region	175[a]	30	205
Total boreal birds	210	40	250

[a] Of the 175, 55 are water birds that winter along the coasts or in southern areas where water bodies remain open; the other 120 are land birds.

Source: Adapted from Erskine (1977).

these wetlands are among its most diverse and biologically productive ecosystems (Sheehy 1993).

Water

Water is a defining characteristic of the Boreal Shield ecozone. The combination of fractures in the Canadian Shield rock and glacial scouring created thousands of disconnected depressions and furrows that are now filled with water. Throughout much of the area, the bedrock modified by glaciation controls the fragmented water drainage pattern, which hydrologists describe as disrupted or disorganized.

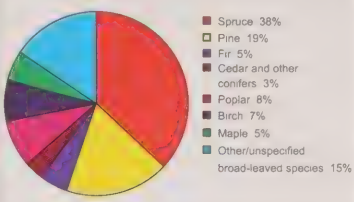
Since human beings first migrated into this ecozone near the end of the last ice age, the Boreal Shield ecozone's sweeping network of rivers and lakes has provided transportation, a rich fishery, and a source of fur-bearing mammals for the trapping economy. More recently, these waters have gained importance as a focus for outdoor recreational activities, such as boating and angling, and for the development of hydroelectric power. To the east, the rocky north shore of the Gulf of St. Lawrence and the coast of Newfoundland support diverse marine life and provide nesting grounds for many seabirds.

Wildlife

Spring runoff in the Boreal Shield ecozone attracts hundreds of thousands of land and water birds. They come to the ecozone to breed or to rest and feed before journeying onwards to more northerly nesting grounds (Table 5.1). Some of the pressures that species are experiencing are described in Box 5.1, which focuses on the American Black Duck. Some typical bird species of the Boreal Shield ecozone include the Boreal Owl, Northern Hawk Owl, Solitary Sandpiper, White-throated Sparrow, and Rusty Blackbird, as well as the Downy Woodpecker, Common Raven, and Common Grackle (Downes and Collins 1996).

Two hundred and ten species of birds breed in the Canadian boreal region (i.e., the entire region covered by boreal forest, which extends beyond the Boreal Shield ecozone), 35 of which overwinter there

Figure 5.2
Breakdown of forest tree species in the Boreal Shield ecozone



Source: Canada's National Forest Inventory, Canadian Forest Service, Natural Resources Canada

(Table 5.1). However, very few bird species breed exclusively in the Boreal Shield ecozone (Downes and Collins 1996).

Some mammals that are typical of this ecozone include Woodland Caribou, Moose, Black Bear, Wolf, Canada Lynx, Snowshoe Hare, American Marten, Red Fox, Red Squirrel, and Coyote. The ecozone's many wetlands, ponds, rivers, and lakes are important habitats for furbearers such as beaver, Muskrat, and mink.

Most populations of large mammals seem to be stable or increasing (Bird and Rapport 1986). For example, Woodland Caribou have significant forest habitats in the ecozone, including stable herds in Newfoundland's Avalon Peninsula. In the Quebec portion of the Boreal Shield ecozone, Caribou have practically disappeared. The Val-d'Or herd remains in critical condition owing to its small group size (a few hundred individuals) and land use pressures (C. Potvin, Ministère de l'Environnement et de la Faune du Québec, personal communication).

Lake Trout, Lake Whitefish, Walleye, Brook Charr, and Northern Pike are among the most common fish species of the ecozone's lakes and rivers. Commercial fisheries constitute a major activity, especially on lakes over 1 000 ha in area. Fishing is carried out by Aboriginal peoples and recreational anglers across the Boreal Shield ecozone.

Today, there is concern about a number of wildlife species in this ecozone that are at low population levels (Table 5.2).

Box 5.1
The decline of the American Black Duck

Numbers of American Black Duck, a characteristic waterfowl species of the Boreal Shield ecozone, have been declining in eastern North America for more than 30 years. The Black Duck Joint Venture (BDJV) of the North American Waterfowl Management Plan is gathering vital information to reverse this trend and to ensure sustained populations of American Black Ducks and other waterfowl that share their breeding range.

To develop the databases required to manage American Black Ducks and other eastern waterfowl, the BDJV focuses on three basic tasks: monitoring the status of regional breeding populations, improving banding to determine survival and harvest rates, and supporting research to identify factors responsible for the long-term decline of the species.

The top priority is to develop reliable population estimates and detect changes in numbers of American Black Ducks and other species in eastern habitats. Helicopters are used to survey a set of plots in the heart of the American Black Duck's range in the boreal habitats of Ontario, Quebec, Atlantic Canada, and Maine. Fixed-wing aircraft are used to survey more open country to the south, where there are fewer American Black Ducks but more of a closely related duck species, the Mallard. The helicopter surveys show that numbers continue to decline slowly (Fig. 5.B1), despite harvesting restrictions that have been in place range-wide since the mid-1980s. The decline is especially noticeable in Quebec, where a substantial proportion of the species breeds.

Recoveries of banded birds enable researchers to link causes of mortality with regional population trends. For example, analysis of banding data indicates that, overall, harvesting may not be responsible for population decline, except in a few areas. Banding of American Black Ducks and other species is supported in Canada by both Atlantic and Mississippi flyway states.

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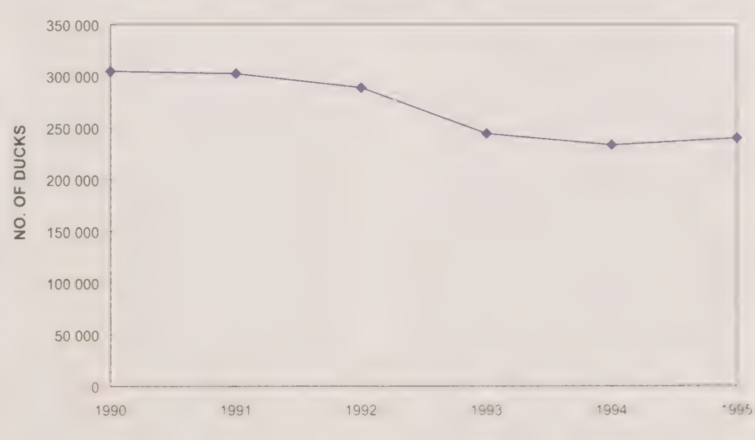
Figure 5.B1
Population index for American Black Ducks measured on plots surveyed by helicopter, 1990–1995



Source: Wyndham and Dickson (1995)

Box 5.1 (continued)
The decline of the American Black Duck

Research supported by the BDJV includes projects to determine habitat-specific productivity of American Black Ducks over large geographic areas, to determine principal variables (i.e., weather, predators, nutrition, etc.) influencing nesting success and recruitment among various breeding habitats, and to evaluate the impacts of various land use practices on habitat use by breeding, migrating, and wintering American Black Ducks.

Despite considerable research interest in the American Black Duck "problem," little scientific evidence has emerged to show definitive cause-and-effect relationships. Debate centres on whether it is productivity, mortality (due to hunting or other factors), habitat change, or interactions with Mallard ducks (through either hybridization or competition for habitat) that has caused the decline of the American Black Ducks. Some observers believe that the decline is likely due not to a single factor but to a combination of factors that could vary across the American Black Duck's range.

Figure 5.3
Major population centres in the Boreal Shield ecozone

Source: State of the Environment Directorate, Environment Canada.

Socioeconomic setting

The vast forests, rich mineral deposits, countless lakes, and abundant wildlife resources of the Boreal Shield ecozone are vital parts of Canada's natural resource base. The ecozone ranks fourth among Canada's 15 ecozones for its estimated 1991 gross domestic product of $49 billion (8% of the Canadian total), and its total income of $41.8 billion represents 9% of Canadian wages. Per capita income in the ecozone is low (ranking seventh) at $14 768, compared with $18 646 in the Pacific Maritime ecozone, also a natural resource-based ecozone (special tabulation prepared by Statistics Canada for the State of the Environment Directorate, Environment Canada, based on the 1991 Census).

Population

Ten percent of Canada's population lives in the Boreal Shield ecozone, mostly in the centres of the southern and eastern portions of the ecozone (Fig. 5.3). Between 1971 and 1991, the total population increased by 11% to 2 831 824, a rate of increase some 15% slower than the Canadian average. Overall population density is quite low, at about 1.5 people per square kilometre, and is split roughly 60/40 between urban and rural areas (Fig. 5.1b).

In Canada, the total Aboriginal population is just over 1 million persons, 60% of whom live in rural or remote areas. Nearly half the Aboriginal population is composed of registered Indians, and 28% of these (160 000) reside in the Boreal Shield ecozone.

Most inhabitants of the ecozone live in settlements ranging in size from 1 000 to 30 000 residents. The largest urban centre is St. John's, Newfoundland, with a 1991 population of some 170 000 people; Figure 5.1c illustrates the population levels and shifts in levels in selected centres. Several one-resource towns have experienced significant and often sudden depopulation resulting from the closure of local mines or mills. Flin Flon, Manitoba, for example, lost 26% of its population between 1981 and 1991; Schefferville, Quebec, lost 85%; and Uranium City, Saskatchewan, lost almost its entire population (from 2 500 to less than 100) (Bone 1994; Lee 1994). Some communities are seeking innovative ways to reverse this decline. For instance, after the closing of the uranium mine in Elliot Lake, Ontario, the town attracted several thousand people looking for a quiet community for retirement (Dutton 1994).

Labour and employment

The economy of the Boreal Shield ecozone is based on its natural resources. Fifteen percent of Canada's resource-related employment occurs in the ecozone. In the ecozone as a whole, 7.7% of the 1991 labour force was employed directly in such primary sector activities as resource extraction and harvesting. Twelve percent were employed in secondary manufacturing and processing of resources, whereas 76% worked in the tertiary sector, mostly in commercial services, construction, and government. In the last 10 years, the trend in the primary and secondary labour force has been down, whereas that in the tertiary sector has been up. The growing tertiary sector in this ecozone reflects general trends towards growth in the tourism and service sectors, technological change in resource extraction, and government decentralization initiatives.

Within the primary labour force, mining and forestry are the number one employers, followed by fisheries and then agriculture (Fig. 5.1d). In the manufacturing sector, the pulp and paper industry employs the largest proportion of workers. Many people are still involved in fishing

Table 5.2
Some characteristic species of the Boreal Shield ecozone that are endangered or threatened

Group	Endangered			Threatened		
	Species	Province	Reasons	Species	Province	Reasons
Mammals	Cougar (eastern)	Ont., Que.	Unknown, naturally rare	Newfoundland Marten	Nfld.	Habitat destruction (old-growth forest)
Fish	Aurora Trout	Ont.	Acidic deposition, pollution	Blackfin Cisco	Ont.	Exploitation by commercial fishing
				Shortjaw Cisco	Ont., Man.	Exploitation by commercial fishing
				Channel Darter	Que., Ont.	Sedimentation in aquatic habitat
Plants	Engelmann's Quillwort	Ont.	Habitat destruction, chemical contamination	Athabasca Thrift	Sask.	Habitat destruction following road construction
				Tyrrell's Willow	Sask.	Habitat destruction following road construction
				Pitcher's Thistle	Ont.	Habitat destruction on sand beaches
				Blunt-lobed Woodsia	Ont., Que.	Habitat destruction

Source: K. Ross, Canadian Wildlife Service, Ontario Region, personal communication.

and hunting, an important tourism-related activity that employed 6.2% more people in 1991 than a decade earlier. During the same period, employment in service industries rose 23%, whereas that in forestry dropped 16% (National Database, State of the Environment Directorate, Environment Canada). (The importance of natural resources to Canada is elaborated on in Chapter 11.)

Land use
Land use patterns in the Boreal Shield ecozone reflect the geographic distribution of resources as well as the evolution of its transportation systems. Its vast forests support such activities as logging, wood fibre and sawlog production, pulp and paper mills, and fibre board production. Its wealth of minerals supports prospecting, mining, and smelting activities. Its plentiful waters support large-scale hydro developments spurred by the energy requirements of southern centres and the need to process wood and minerals within the ecozone.

Natural landscapes and abundant wildlife and fish support Aboriginal subsistence, sport, and commercial harvesting activities, as well as a growing ecotourism industry. The many established protected areas include national and provincial parks that attracted more than 7 million visitors in 1993–1994 (Table 5.3). As well, extensive areas of the ecozone have special designations or protected status. Development of this protected area network is an important step towards ensuring continued viability of the Boreal Shield ecozone's ecosystems. Table 5.4 shows the amount of protected space in the ecozone, summarized using the World Conservation Union's (IUCN's) classification system for protected areas (see Chapter 14, Box 14.4, for an explanation of the IUCN categories). Protected areas in IUCN categories I–III are those that are most strictly protected from human influence. IUCN categories I–VI represent the total of all protected space in the ecozone. Between 7% and 8% of the total area of the ecozone, or some 14.4 million hectares, has some protected status. The target set globally by the World Commission on Environment and Development for the protection of a representative sample of the Earth's ecosystems is 12%. Most of the area under protection in the Boreal Shield ecozone was established prior to the 1980s, with 1.9% being added between 1980 and today. (Chapter 14 gives a national overview of biodiversity protection.)

Agriculture in the ecozone is limited; most farming activities are restricted to the so-called "clay belt" area in north-central Ontario and Quebec. Limited agriculture occurs in scattered pockets throughout the ecozone where local climate and soils are favourable, such as around Lac Saint-Jean in Quebec. The majority of farms are relatively small, producing livestock, dairy cattle, and hardy vegetables, fruits, and grain crops such as oats and barley. Wild rice, blueberries, cranberries, and peat are harvested from some wetland areas (Dilley 1994). Agriculture is declining throughout the ecozone, even though it contains some particularly productive areas — for example, in Quebec.

Table 5.3
National and provincial parks in the Boreal Shield ecozone, 1994

Province	Type	Name or number	Area (km²)	1993–1994 attendance
Newfoundland	National	Gros Morne	1 805	130 000
		Terra Nova	400	250 000
	Provincial	78	313	1 614 900
Quebec	National	La Mauricie	544	250 000
		Mingan Archipelago	97	25 000
	Federal/provincial	Saguenay National Marine Park	1 138	N/A
		Gatineau (administered by the National Capital Commission)	357	N/A
	Provincial	6	3 088	1 571 900
Ontario	National	Pukaskwa	1 878	13 000
	Provincial	69	29 335	3 329 200
Manitoba	Provincial	14	10 448	N/A
Saskatchewan	Provincial	2	5 286	N/A
Total			54 689	7 184 000

N/A = not available

Source: Manitoba Natural Resources (1991); Government of Newfoundland and Labrador (1993); Parks Canada (1994); Ontario Ministry of Natural Resources (1995); Saskatchewan Environment and Resource Management (1995); R. Daigle, Ministère de l'Environnement et de la Faune du Québec, personal communication.

Table 5.4
Protected areas in the Boreal Shield ecozone, 1960–1994

Year	IUCN[a] categories I–III		IUCN categories I–VI	
	No. of sites	% of area	No. of sites	% of area
1960	153	0.5	171	3.0
1980	300	1.3	382	5.5
1990	450	2.8	569	7.3
1994	468	2.8	601	7.4

[a] World Conservation Union, formerly International Union for the Conservation of Nature and Natural Resources.

Source: National Conservation Areas Database, State of the Environment Directorate, Environment Canada.

Commercial fisheries are locally important in Atlantic coastal regions of the Boreal Shield ecozone (see Chapter 7 for a discussion of marine fisheries). However, since the early 1990s, groundfish populations have declined dramatically owing to intensive fishing and changing natural conditions (Eaton et al. 1994). The closure of the fishery will force communities to turn to other natural resources for their economic survival, thereby increasing pressures on land resources, particularly in Newfoundland (McLaren 1994).

Transportation routes have been central to the development of this large part of Canada (Wightman and Wightman 1992). Isolated road and rail networks link scattered resource towns to larger southern centres. Completion of the Trans-Canada Highway in the 1950s was an important development catalyst for the area. The sporadic construction of new secondary roads continues to improve access to some regions. On the other hand, recent decreases in passenger rail, airline, and bus services to many smaller communities have had the reverse effect. Like transportation corridors, the area occupied by urbanized areas on this landscape is small — only 322 km². Although much of the Boreal Shield ecozone remains in a relatively natural state, the reach of human activities extends far beyond the roadbed, railway tracks, or urban fringe.

The Changing Forests

Natural disturbances

Disturbances such as fire, insects, disease, and wind affect the structure and function of the boreal forest. These disturbances are natural processes to which forest plants, animals, and microorganisms have adapted. The extent to which such disturbances affect different aspects of the boreal forest depends on several factors, key among them being climate, forest age-class and type, and forest management policies. Discussion here focuses on fire and insect infestations, the dominant natural disturbances of the Boreal Shield ecozone.

Fire

The natural cycle of fire varies greatly within the Boreal Shield ecozone, from 70–80 years in northwestern Ontario, through 200 years in north-central Quebec, to perhaps 500 years in south-central Labrador (Foster 1983; Payette et al. 1989; Zoladeski and Maycock 1990; Archambault and Bergeron 1992). Nationally, more than 7.5 million hectares, many of them in boreal Canada, burned in 1989, making it the most severe fire year on record. In that year, large areas burned in Manitoba (over 3 million hectares) and Quebec (over 2 million hectares) (Canadian Council of Forest Ministers 1995). The area burned in 1995, once tallied, is expected to surpass this total (see Chapter 11).

Figure 5.4 displays the 10-year running average, from 1920 to 1992, of area burned within the Boreal Shield ecozone. Across

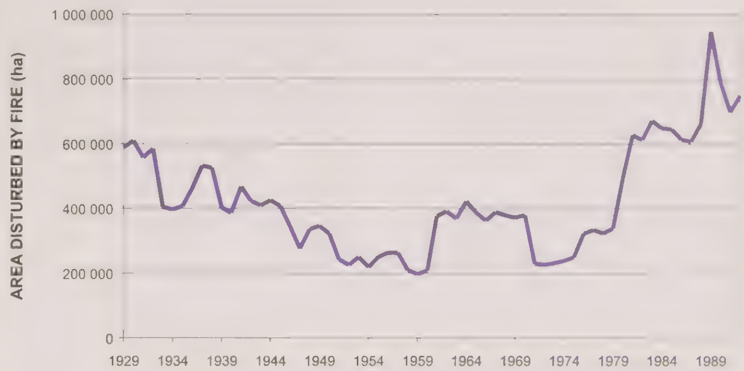
Canada, lightning starts 40–50% of all fires (Canadian Council of Forest Ministers 1995). Lightning fires often burn in remote areas where suppression is not carried out; they account for approximately 85% of the total forested area burned (Van Wagner 1991; Canadian Council of Forest Ministers 1995). Across the ecozone as a whole, fire remains a major disturbance factor despite fire suppression, and in recent years the annual burned area has been much larger than in any year between the 1940s and the 1970s. This contrasts with reductions in the burned area in the Montane Cordillera and Pacific Maritime ecozones, where fire suppression has reduced wildfire substantially (see Chapter 3).

Insects

Insects are important agents of change in the boreal forest, affecting far larger areas annually than do forest fires. Large-scale infestations often occur in cycles, triggered by some optimal mix of climate, predator, and disease factors. Common insect pests include the Spruce Budworm, Forest Tent Caterpillar, Jack Pine Budworm, Mountain Pine Beetle, Gypsy Moth, and Hemlock Looper. Most infestations do not kill stands outright. However, two or three consecutive infestations may so weaken stands that they become susceptible to diseases that eventually kill them (see Chapter 11).

Historically, the Spruce Budworm has been the dominant infestation within the Boreal Shield ecozone. Repeated Spruce Budworm outbreaks in eastern Canada have been documented as far back as the early 1700s. Two severe outbreaks between 1910 and 1920 are estimated to have destroyed up to 720 million cubic metres of timber (Shugart et al. 1992). Major recent infestations occurred in the 1940s, 1950s, 1970s (over 50 million hectares affected), and early 1980s. Current infestations approximate 10 million hectares annually. In the early 1990s, the Forest Tent Caterpillar ravaged close to 10 million hectares annually just within Ontario. Recent data for the Forest Tent Caterpillar show declines in areas infested to below 1 million hectares (Canadian Council of Forest Ministers 1995).

Figure 5.4
Trends in forest fires in the Boreal Shield ecozone, 1929–1992



Note: 1. Data before 1980 are less reliable.
2. Data are 10-year running averages.

Source: ESSA Technologies Ltd. (1993); Canadian Forest Service, Natural Resources Canada.

Human disturbances

Harvesting practices

The Boreal Shield ecozone, with 106 million hectares of timber-productive forestland, has close to half of Canada's total.

Most of the harvesting is carried out for pulp and paper production, which takes place at 37 mills throughout the ecozone (J. Ducharme, Canadian Pulp and Paper Association, personal communication). (See Chapter 11 for a discussion of environmental concerns and initiatives associated with pulp and paper mill operations and effluent.) However, the fuelwood harvest within Newfoundland accounts for approximately 25% of that province's total harvest. Quebec and Ontario, which contain the bulk of the timber-productive forest of the Boreal Shield ecozone and 40% of Canada's commercial forest, account for 40% of the national allowable annual cut (AAC) (Natural Resources Canada 1995).

As a whole, the annual area harvested has doubled to approximately 400 000 ha since the 1920s (Fig. 5.5). This is about half the total area harvested in Canada. Annual fluctuations in harvest reflect prevailing economic conditions. The largest harvest occurred in 1987, when 500 000 ha were cut.

On the island of Newfoundland, the softwood harvest has reached or exceeded the AAC for that province. Short-term shortages for mills occur, and logs have to be imported from Labrador and elsewhere. Harvests within Quebec and Ontario are generally well below AACs, although regional shortages do occur. Similarly, harvests in the boreal forests of Manitoba and Saskatchewan are well below AACs for both softwoods and hardwoods (Natural Resources Canada 1995).

It is expected that some AACs will decrease in the short and medium term. Reasons include the potential reduction of the land base available for timber production as more forested land is set aside for other uses; the trend towards a younger age-class structure of the forest; and the move towards an ecosystem approach to forest management, which may change some operational practices that could lower AACs (see Chapter 11).

Approximately 90% of all harvesting is carried out through clear-cutting. Two harvesting systems dominate: full-tree and tree-length. Under the full-tree harvest system, the cut tree, including limbs and foliage, is taken to roadside for delimbing. With the tree-length system, the branches and foliage are removed on site, and only the trunk is taken to roadside. This latter system removes less biomass and nutrient material from the site.

Clear-cutting is a controversial practice because of ecological concerns. Forest managers argue that the clear-cut harvesting system is the most ecologically sound for boreal forest ecosystems, as it enables both economical removal of timber and establishment of site conditions conducive for regeneration. It should be noted that an independent environmental assessment board in Ontario stated that "clear cutting is an acceptable timber management practice, particularly in the boreal forest" (Ontario Environmental Assessment Board 1994). Those opposed to clear-cutting argue that the practice is not ecologically sustainable, may cause considerable loss of forest soil and water quality, and may adversely affect biodiversity (see Chapter 11).

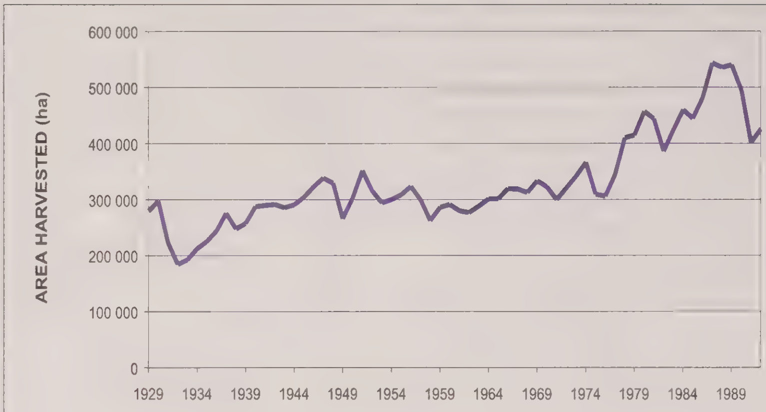
Fire, insect, and disease suppression

Fire suppression is a major forest management tool for protection of property and stands of commercial timber. It can also greatly affect the long-term natural cycle of forest fires. As an example, in the south-central Ontario portion of the Boreal Shield ecozone, fires burn a stand approximately every 578 years, consuming a total of roughly 81 000 ha of forest each year. Before fire control policies were implemented, fires burned a stand every 65 years, and the average area affected was approximately 720 000 ha annually (Natural Resources Canada 1995).

The implications of fire suppression for the natural succession of the boreal forest and for habitat distribution and change are unknown. Wildlife researchers are studying this issue and its potential impacts on existing wildlife. Other researchers are analyz-

Figure 5.5

Annual area of forest harvested in the Boreal Shield ecozone, 1929–1992



Source: ESSA Technologies Ltd. (1993); Canadian Forest Service, Natural Resources Canada.

Box 5.2

Canadian boreal forests: net source or sink of carbon?

For thousands of years, the Canadian boreal forests have undergone cycles of disturbance (fire- and insect-induced mortality) and regrowth. Where a stand of trees is destroyed, new trees — mostly of similar age — grow up to replace it. These forests are major stores of carbon and sources of carbon (as carbon dioxide) to the atmosphere. Whether the forests act as a net source or sink of carbon is a major topic of research because of the implications for global climate change.

Until recently, it was thought that carbon flowed between the forests and the atmosphere at a relatively constant rate and that, generally, the forests took up more carbon than they released. Current research, however, suggests that this may not be the case in these forests, whose growth cycle is dominated by — and even depends on — cycles of natural disturbance. This research indicates that the frequency of disturbance cycles may be intimately linked to whether the forests act as a net source or sink of carbon. It also suggests that forest management activities — fire suppression and insect control — may be influencing the frequency of natural disturbance cycles.

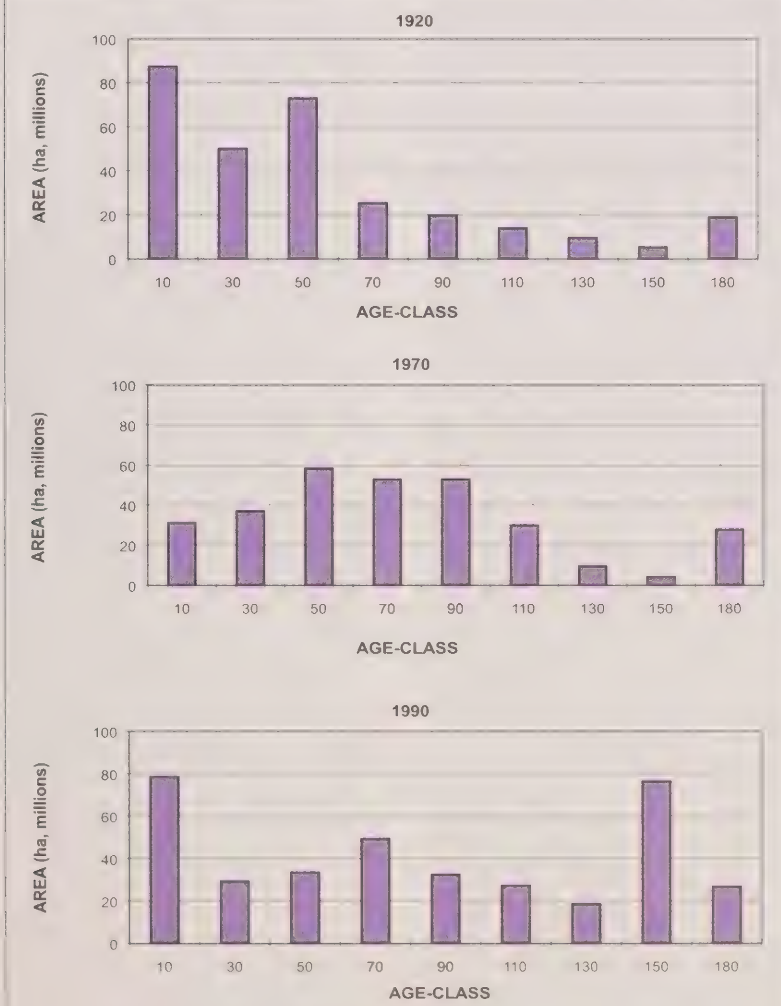
The frequency of natural disturbance cycles can be inferred from examining the changing age-class structure of the forests. Research by Kurz and Apps (1996) indicates that in 1920 the younger age-classes were predominant, suggesting that natural cycles of disturbance were more closely spaced in time than at present (Fig. 5.B2). Between 1920 and 1970, the average age of the boreal forest increased from 60.9 to 82.5 years. This increase was due to a decrease in forest fires following the introduction of fire suppression policies in the 1920s. Between 1970 and 1989, however, the average age of the forest declined to 76.4 years. The cause was a twofold increase in natural disturbances resulting from various factors, including new fire suppression policies that allowed more remote fires to burn, increased ground fuel supplies, and unusually warm, dry summers.

continued on next page

Box 5.2 (continued)
Canadian boreal forests: net source or sink of carbon?

Kurz and Apps (1996) conclude that periods of high disturbance result in a net transport of biomass carbon from living vegetation to the soil. Through decomposition, soil carbon is eventually released into the atmosphere. The increased disturbances of the 1970–1989 period have enlarged this pool of soil carbon. In the coming years, it will be released to the atmosphere, perhaps making the Canadian boreal forest a net source of atmospheric carbon.

Figure 5.B2
Forest age-class structure of Canadian boreal forests in 1920, 1970, and 1990



Note: Each age-class (10, 20, 30, etc.) represents the midpoint of a 20-year age range. For example, age-class 30 includes trees aged 21–40 years; age-class 70 includes trees aged 61–80 years.

Source: Kurz and Apps (1996)

ing the impact on stand structure and age-class over time and the resulting implications for the carbon budget of the boreal forest (Box 5.2) (Kurz and Apps 1996).

Like fire, insect and disease infestations are parts of the life cycle of Canadian forests. They are necessary for the perpetuation of healthy forests. However, there are concerns over the economic losses to the forest industry from infestations within the commercial forest. For environmental reasons, many forest managers now use biological rather than chemical insecticides to combat these infestations (see Chapter 11).

Nationally, pesticides (insecticides and herbicides) were used on 256 000 ha in 1993, down from over 1 million hectares in 1990. Pesticides for forest use within Canada account for only 2% of the total Canadian pesticide use (see Chapter 11).

The biological insecticide Bt (*Bacillus thuringiensis*) has been the insecticide of choice for the past few years, being applied on 65% of the sprayed area (Canadian Council of Forest Ministers 1995).

Within the Boreal Shield ecozone, Quebec, Ontario, and Newfoundland have been the primary insecticide users. Quebec stopped using all pesticides (insecticides and herbicides) in 1993; Ontario's use is minimal.

Forest herbicide use has always been low. Between 1988 and 1993, annual herbicide application fluctuated between 139 000 and 233 000 ha nationally. For the provinces of the Boreal Shield ecozone, total herbicide application reached a high of 142 000 ha in 1990 and a low of 67 000 ha in 1993.

Acidic deposition
Major smelters and thermal generating stations in central Canada and the United States are the main remote sources of sulphur dioxide and nitrogen oxides falling on the Boreal Shield ecozone. Prevailing weather patterns tend to carry the emissions over the ecozone, especially its Ontario and Quebec portions. Acidic deposition can affect forests, soils, and

Box 5.3
Acidic deposition in the Boreal Shield ecozone

Acidic deposition remains a serious environmental problem in Canada. It is caused by emissions of sulphur dioxide and nitrogen oxides, which are converted to sulphuric acid and nitric acid, respectively, in the atmosphere. The largest Canadian sources of sulphur dioxide are the smelting or refining of sulphur-bearing metal ores and the burning of fossil fuels for energy. The Boreal Shield ecozone includes six base metal smelters that were responsible for 37% of total eastern Canadian sulphur dioxide emissions in 1994. Nitrogen oxides are formed during the combustion of fossil fuels in transportation, power generation, and heating.

Once released into the atmosphere, acidic pollutants may be transported great distances by the prevailing winds and weather systems before being deposited in wet form as precipitation or fog or in dry form as acidic gases or dust. It is estimated that more than 50% of the acidic deposition that falls in eastern Canada comes from sources in the United States. Parts of Ontario and Quebec situated within the Boreal Shield ecozone are directly affected by emissions from the United States.

Much of this ecozone is sensitive to acidic deposition, as its mainly thin, coarsely textured soil and granitic bedrock have little inherent ability to neutralize acidic pollutants. As a result, acidic deposition may contribute to declining growth rates and increased mortality in trees. For example, instances of dieback and decline have been noted in Sugar Maples in parts of Ontario and Quebec that receive high levels of acidic pollutants.

High levels of acidic deposition can also result in the acidification of acid-sensitive lakes, rivers, and streams and cause metals to leach from surrounding soils into the water system. High acidity and elevated levels of metals can seriously impair the ability of water bodies to support aquatic life, resulting in a decline in species diversity and undesirable impacts on water-dependent wildlife (McNicol et al. 1995). Increased acidity results in losses of certain fish species, increases populations of acid-tolerant invertebrates, and retards waterfowl growth and reproduction rates. Increased acidity is a special concern in the eastern part of the Boreal Shield ecozone, as it results in the loss and degradation of habitat for fish, amphibians, and continental waterfowl.

In the mid-1980s, evidence of environmental damage caused by acidic deposition led to renewed efforts to control sulphur dioxide emissions. A Canadian Acid Rain Control Program was formalized in 1985 with the establishment of agreements between the federal government and the seven easternmost provinces. Participating provinces agreed to reduce their combined emissions to 2.3 million tonnes per year by 1994. This target was exceeded in 1993, and by 1994 total eastern Canadian sulphur dioxide emissions were 1.7 million tonnes. These emission reductions are a result of industrial process changes, scrubber installation, and use of alternative fuels by companies such as Inco, Noranda, and Ontario Hydro.

In 1991, Canada signed an air quality agreement with the United States, which includes mutual obligations for reducing sulphur dioxide and nitrogen oxide emissions. However, even with full implementation of the Canada–U.S. Air Quality Agreement, some acid-sensitive regions in eastern Canada will continue to receive elevated levels of acidic deposition.

The acidity of lakes and streams in areas that receive high levels of acidic deposition is being monitored (Environment Canada 1996). Only in the Sudbury region of Ontario do the majority of monitored lakes show reduced acidity over the past decade. This is attributed to the substantial control of sulphur dioxide emissions from Sudbury's nickel smelters. However, despite emission controls in eastern Canada, lakes in the rest of Ontario, Quebec, and Newfoundland show little reduction in acidity, primarily due to the continuing flow of acidic pollutants from the United States.

human health. However, it has a particularly pronounced effect on surface waters, especially in areas without alkaline rocks and soils that can neutralize deposited acids, such as much of the eastern Boreal Shield ecozone.

The signing of the Canada–United States Air Quality Agreement in 1991 marked progress towards the control of acidic air pollutants. Nevertheless, this ecozone's sensitive environment is still being affected by acidic deposition (Box 5.3).

Climate change

The burning of fossil fuels and other human activities that have led to net global deforestation have increased atmospheric concentrations of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. A rise in average global air temperature of approximately 0.5°C over the past century has been attributed, at least in part, to this "enhanced greenhouse effect" (see Chapter 15). If measures are not taken to stabilize, and preferably reduce, anthropogenic greenhouse gas emissions, scientists believe that significant climate change could occur. The potential consequences of such change for boreal ecosystems have been the subject of considerable speculation (e.g., Pruitt 1993). Forest changes themselves could affect climate warming in unknown ways, as large amounts of carbon are stored in and released from the boreal forest (Shugart et al. 1986; Kurz et al. 1990; Bonin et al. 1992).

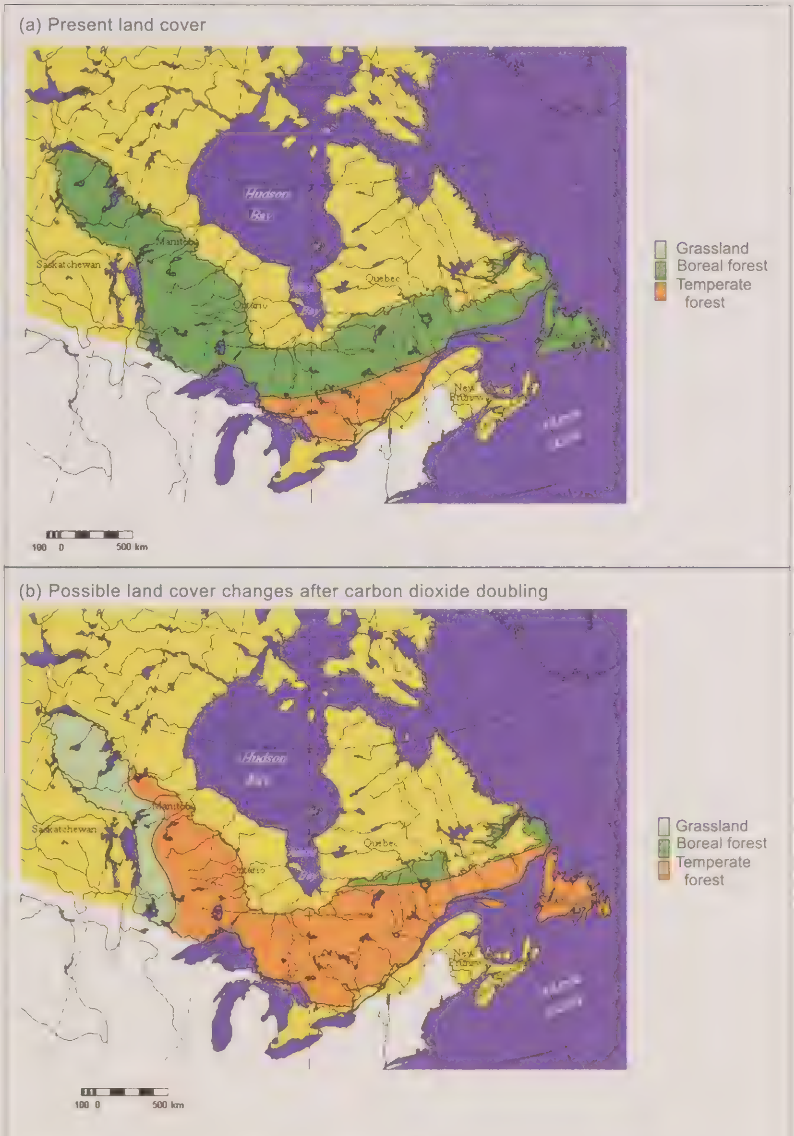
A warmer climate could have widespread effects on forest stability, tree species composition, insects and diseases, and forest fire frequency. In turn, these changes could affect wildlife, fisheries, and agricultural capabilities. From 1985 to 1992, there was a moderate but statistically significant regional warming of 0.5°C for the boreal forest extending from the Manitoba–Ontario border to the south coast of Labrador (Gullett and Skinner 1992).

Some climate change scenarios suggest major changes in land cover in the next century (Fig. 5.6) (Kemp 1994). The current boreal climate and associated plants

and animals would probably shift northward to the area currently occupied by the Taiga Shield and Hudson Plains ecozones. Meanwhile, the present area of the Boreal Shield ecozone could take on some characteristics of the present Prairies, Mixedwood Plains, and Atlantic Maritime ecozones (Rizzo and Wiken 1992).

Forecasting the effects of a warmer climate is complicated by many uncertainties, notably the extent of warming itself and the sensitivities of species and ecosystems to warming (Goos and Wall 1994). To address such uncertainties, an international team of scientists recently began a multiyear study called BOREAS to examine forest–atmosphere relationships (Box 5.4) (Energy, Mines and Resources Canada 1993a; Stewart 1995).

Figure 5.6
How carbon dioxide doubling could change land cover



Source: National Atlas Information Service, Natural Resources Canada

Biodiversity

The boreal forests are home to far fewer plant and animal species than are the tropical forests. Nevertheless, the soils of the Boreal Shield ecozone teem with microorganisms, and the varied ecosystems that make up the ecological mosaic of the ecozone are home to a multitude of birds, mammals, fish, insects, and other wildlife. Loss of this biodiversity as a result of human activities is a concern in this ecozone, as it is for all the ecozones of Canada (Box 5.5).

The major human activities in the Boreal Shield ecozone are forest harvesting and related forest management activities. However, it is unclear whether these activities will cause long-term reductions in biodiversity, as it is difficult to measure changes in biodiversity or to assess whether observed changes are within the limits of natural fluctuation.

The vegetative composition of the forest — its tree species and age-class structure, shrubs, and ground flora — its suitability as habitat, and its role in functions such as nutrient and water cycling are intimately connected to biodiversity. Data are sparse or nonexistent on many aspects of these ecosystem components. However, Canada's National Forest Inventory database enables some generalizations to be made about species composition and age-class structure and the impact of human activities. Data for accessed and nonaccessed portions of forestland can serve as surrogate data for areas affected by human activity and areas receiving relatively little human intervention.

Age-class distribution and old growth

A complex system of ecological characteristics encompassing species, age-class, site conditions, and amount of snags and ground debris are some of the variables used to define old growth. Many different types of old-growth forest exist within

Canada (Duchesne 1994; see also Chapter 11). The Boreal Shield ecozone is dominated by stands that grow out of forest areas that have previously been burned. The life span of these stands has historically not exceeded 100–150 years (Payette 1992).

No broad-scale inventories of old-growth forest exist for the Boreal Shield ecozone. However, an analysis of the general age-class distribution for the timber-productive forest (70% of the ecozone) indicates a higher percentage of younger forest in the accessed forest (Fig. 5.7) (Environment Canada 1995; Lowe et al. 1996). This differential in age-class between accessed and nonaccessed timber-productive forestland probably reflects a harvesting history. Over 45% of the nonaccessed timber-productive forest is older than 100 years, compared with approximately 17% of the accessed portion. No data are available for the nontimber-productive portion of the ecozone.

Box 5.4
BOREAS: unlocking the secrets of the boreal forest

Named after the mythical god of the north wind, BOREAS (the Boreal Ecosystem–Atmosphere Study) is the largest international field study of its kind ever conducted. Covering 1 million square kilometres of the boreal forest, this study is intended to improve understanding of the interactions between the Earth's climate system and the boreal forest and to clarify their respective roles in global climate change. A primary objective of BOREAS is to collect the data needed to improve computer simulation models of the processes controlling these exchanges.

Research will focus on the biogeochemical cycles underlying land surface–atmosphere interactions and ecosystem dynamics; the energy–water cycles underlying these interactions and their implications for climate change; and the implications of climate change for boreal ecosystem structure, function, and dynamics. In addition, BOREAS will develop and test satellite remote sensing techniques to transfer understanding of the above processes from the local scale to regional and global scales.

BOREAS is led jointly by the U.S. National Aeronautics and Space Administration (NASA) and the Canada Centre for Remote Sensing. Scientists from several countries, including Canada, the United States, France, the United Kingdom, the Russian Federation, and the Scandinavian countries, will participate.

Planning for the study began in the late 1980s; in 1992, two regional field sites were selected. Preliminary fieldwork began in 1993, and the main fieldwork in 1994. Two years of analysis and theoretical studies are to follow.

The two field sites were selected at extremes in the Canadian boreal forest. The locations were relatively undisturbed, typically boreal, and close to supporting infrastructure, such as airports and communications. The southern site is located in the Prince Albert National Park/Candle Lake area of Saskatchewan, and the northern site in the area between Thompson and Nelson House, Manitoba.

Scientists can study land–atmosphere interactions and ecosystem dynamics under different climate conditions at the two sites: the northern location, with a cold, short growing season, and the southern location, with warmer, drier conditions. By comparing results at the two sites, scientists hope to be able to predict how any future climate change might affect the boreal forest.

Preliminary results yield a surprising picture of the energy, water, and carbon dynamics of the boreal ecosystem. The biggest surprise is that the boreal forest, although generally thought to be a wet ecosystem, releases very little water vapour to the atmosphere and appears to the atmosphere as a desert — a green desert. Most of the incoming solar radiation is intercepted by vegetation canopies rather than by the moist underlying moss/soil surface. Moreover, many areas have low water-holding capacities: rainfall tends to penetrate through the moss and soil to the underlying semi-impermeable layer and runoff. These insights into energy exchanges should have a significant impact on the development of climate models, most of which characterize the boreal landscape as a freely evaporating surface.

Perhaps the most intensively studied old-growth forests in the Boreal Shield ecozone are isolated stands of ancient Eastern White Pine found mostly in Ontario and Quebec. Dramatic reductions in the old-growth Eastern White Pine have occurred across Manitoba, Ontario, Quebec, and Newfoundland. Some researchers suggest that a mere 0.5% of their original area remains (Quinby 1993). Others calculate that about 5% of Quebec's original 1.2 million hectares remains today (C. Phaneuf, Ministère des Ressources naturelles du Québec, personal communication). Declines in Eastern White Pine are attributable as much to disease (white pine blister rust) as to harvesting (W.J. Meades, Canadian Forest Service, Natural Resources Canada, personal communication). The Temiscaming area contains some Eastern White Pine, Sugar Maple, and Yellow Birch that are over 200 years old, some with diameters exceeding 1.5 m (Chevalier 1993). Very old cedars ranging in age from 300 to at least 870 years were recently discovered near Lac Duparquet, within a forest reserve, in the Abitibi area (Y. Bergeron, Université du Québec à Montréal, personal communication).

In response to growing concerns in Ontario about the conservation of old-growth forests, the Ontario Ministry of Natural Resources adopted a conservation strategy for old-growth Red Pine and Eastern White Pine forest ecosystems in Ontario. The objectives of this strategy, developed with extensive public input, are to protect representative ecosystems of old-growth Red and Eastern White pine in Ontario and, through forest management, to maintain Red and Eastern White pine on the landscape. In Quebec, a network of ecosystem reserves was developed to protect representative biodiversity, including old-growth forests.

Predominant tree species

Black and White spruce and Jack Pine are the main species within this ecozone. Spruce dominates both the accessed and nonaccessed timber-productive areas (Fig. 5.2). In general, however, White Birch and Trembling Aspen are more common in accessed areas. Both species tend to invade and establish in areas after disturbances such as fire or harvesting. Jack Pine and Black Spruce rely on recurring fires to regenerate. The harvest of spruce stands, along with fire suppression, may be behind the lower proportion of spruce in accessed versus nonaccessed forestland.

Trends in forest management

Canada took a major step in the direction of sustainable forestry with the signing of the Canada Forest Accord in March 1992. This agreement includes an innovative program combining research and multistakeholder participation in a model forest network. Three of the 10 established model forests, covering an area of over 2.2 million hectares, lie within the Boreal Shield ecozone (Natural Resources Canada 1993b). These include the Manitoba Model Forest (407 069 ha), the Lake Abitibi Model Forest in Ontario (1 094 690 ha), and the Western Newfoundland Model Forest (707 060 ha). Among the projects at Lake Abitibi are a natural resources inventory, archaeological inventories, and a prototype audit of forest management developed to assess the achievement of sustainable development objectives.

Quebec recently initiated a new ecological survey to complement its traditional forest surveys (Béland et al. 1992). It also launched a pilot project for integrated forest resource management at two sites: the Mastigouche Reserve (157 400 ha) and the des Laurentides reserve (135 400 ha). Quebec's 1994 Forest Protection Strategy promotes initiatives like these, which are aimed at integrating economic and ecological objectives.

In 1994, Ontario approved a new Policy Framework for Sustainable Forests, which now provides overarching direction for forest management in Ontario. This framework makes the sustainability of forest ecosystems a priority, recognizing that the long-term viability of forest-based communities and businesses depends on this. On 1 April 1995, the new *Crown Forest Sustainability Act* came into force, providing legislative support to the 1994 Policy Framework. Ontario is continuing to develop an improved Crown land planning system that will help ensure an ecological approach to planning and the management of Crown land natural resources.

New approaches in comanagement are being launched with Aboriginal peoples, who have traditionally depended on forests and wildlife for sustenance and income through activities such as trapping, hunting, fishing, gathering of plants and herbs, logging, and guiding. Many of these activities fulfil cultural and spiritual needs (Box 5.6).

Improved stewardship of the Boreal Shield ecozone's forest resources looks promising in light of the many strategic initiatives introduced over the past five years. But the promise of sustainable forestry will be fulfilled only to the degree that these plans, programs, and pilot projects can be translated into concrete action across this huge ecozone spanning many diverse jurisdictions.

Box 5.5
Survival of the Newfoundland Marten

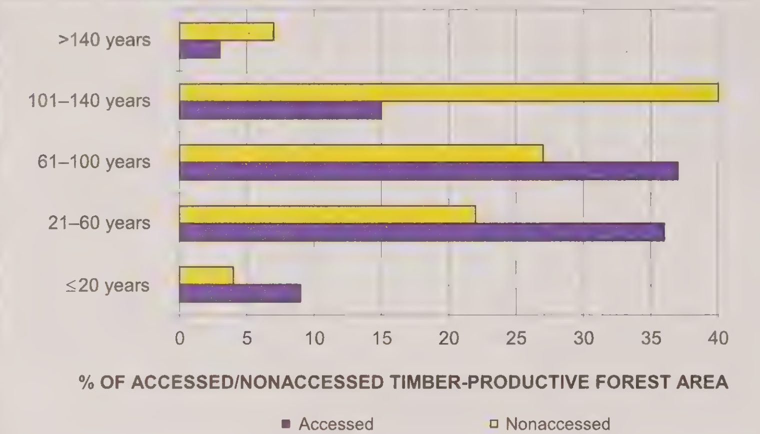
The Newfoundland population of the American Marten has declined dramatically in distribution and numbers over the past 100 years. Many factors are thought to be behind the decline, including predation, disease, overtrapping, and habitat loss due to logging, forest fires, and Hemlock Looper/Spruce Budworm infestations. More recently, the use of all-terrain vehicles and snowmobiles by trappers on the large and expanding network of logging roads has resulted in more accidental trapping and snaring (i.e., marten are caught in traps set for other animals) (Forsey et al. 1995).

Across Canada, marten populations began declining in 1922 and did not rebound significantly until 1959–1960 (Novak et al. 1987). The Newfoundland population never rebounded despite being protected from commercial trapping since 1934 — there are probably fewer than 300 marten left (Bissonette et al. 1988). The Newfoundland Marten exists at substantially lower densities in Newfoundland than elsewhere in North America and is restricted to a few isolated areas of mostly mature and old forest in western Newfoundland (Bergerud 1969; Snyder and Hancock 1983) and in Terra Nova and Gros Morne national parks (Bateman 1985). The Newfoundland Marten was assigned "threatened" status by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1986.

A Pine Marten Recovery Team for the Recovery of Nationally Endangered Wildlife (RENEW) was established in 1990 to devise a plan to reestablish the animal. The goal is to eventually increase the Newfoundland Marten population to at least 1 000 individuals. The team hopes to establish three marten reserves around the island. Field research includes a regular inventory of the numbers and distribution of marten plus an evaluation of experimental logging methods to determine what techniques might be compatible with marten conservation.

As of 1992, no official marten reserve had been established. However, the Western Newfoundland Model Forest near Corner Brook contains suitable marten habitat from which all cutting is now excluded; an environmental assessment area of some 200 000 ha within the model forest excludes both logging and trapping. Logging can continue in prime marten habitat in the Little Grand Lake Area, but only if the main forestry company in the area, Corner Brook Pulp and Paper Co., conducts regular environmental assessments of its activities (Minty et al. 1993).

Figure 5.7
Age-class distribution of forests in the Boreal Shield ecozone, 1991



Note: Data were compiled by accessed versus nonaccessed portions of the forest; a forest was considered accessed if there was a road within 10 km.

Source: Canada's National Forest Inventory, Canadian Forest Service, Natural Resources Canada.

Box 5.6
New approaches in forest management: comanagement

One of the strategic directions of the 1992 Canada Forest Accord was to increase the participation of Aboriginal peoples in forestland management. Several comanagement agreements have since been developed among First Nations people, governments, and forestry companies. These agreements typically result in an integrated forest management plan that combines traditional knowledge of the land with conventional scientific information.

In the Boreal Shield ecozone, the Algonquians of Barrière Lake, Quebec, participate in comanagement agreements that incorporate the notion of community forests — forests whose management is strongly influenced by those who rely on them most. The agreements also lay the foundation for creating resource management boards or advisory bodies in which Aboriginal groups are given equal representation with government agencies and industry.

Mining the Shield

Mineral resource base

Although mining occurs in all six provinces of the Boreal Shield ecozone, it is concentrated in north-central Quebec and Ontario and in northern Saskatchewan and Manitoba (Fig. 5.8). Mining is the economic mainstay of more than 80 communities, ranging from small villages and towns to large regional centres such as Sudbury, Timmins, Rouyn-Noranda, Val-d'Or, Flin Flon, Thompson, Labrador City, and Elliot Lake. Production is estimated at over $6 billion annually (Energy, Mines and Resources Canada 1993b). Most minerals produced are upgraded or refined in the region, further contributing to job creation and enhancement of the local economies. Mining development often drives the building of infrastructure such as transportation and communication networks, power lines, hospitals, and schools (see also Chapter 11).

Development impacts

Land

The impacts of mining activity and the amounts of land disturbed vary depending on the mining stage — exploration, extraction, milling, processing, or decommissioning. Exploration requires temporary access to large tracts of land in order to increase the chances of finding an economic mineral deposit; however, ecosystem impacts are typically localized and short-term. Milling and processing require much smaller tracts of land, but their impact — in terms of tailings and waste rock disposal as well as the mine site and associated infrastructure — is much more significant and longer-term. Mining development also increases access to remote areas, leading to long-term pressures associated with an increase in nonmining activities, such as hunting and recreational activities. Such impacts are outside the direct control of the mining companies.

The total land area occupied by mining is about 550 km^2, or about 0.03% of the ecozone — less than the area occupied by Metropolitan Toronto. Existing and new mining facilities are now required to reclaim the land they disturb in accordance with government-approved reclamation plans. Of the total land area disturbed by mining, about 10% has been rehabilitated or revegetated to date, whereas much of the remainder is still in use (Ontario Mining Association 1993; Nault 1994). Table 5.5 shows the area disturbed by mining and the area rehabilitated to date in Quebec. Current regulations do not permit existing or new operations to abandon sites, as has been done historically.

Air

The smelters used by the metallurgy industry and the iron blast furnaces used by the mining industry require high operating temperatures and emit various pollutants directly into the local atmosphere: particulate matter, nitrogen oxides, sulphur dioxide, metals, and organic compounds. Such substances may be deposited locally or transported over long

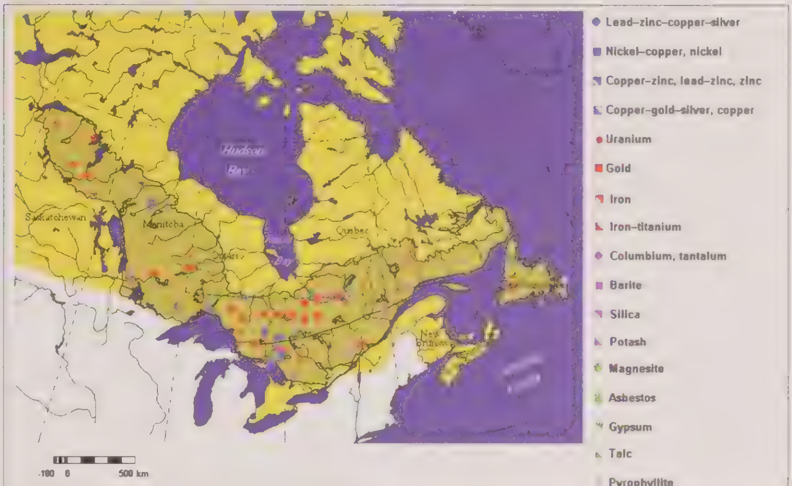
distances; heavy metals are deposited within a 30- to 50-km radius of the stack. Smelter facilities are located at Flin Flon and Thompson, Manitoba, Sudbury and Timmins, Ontario, and Noranda, Quebec; Sault Ste. Marie, Ontario, has an iron blast furnace.

Sulphur dioxide is a major contributor to acidic deposition, which acidifies lakes, rivers, and soils and can adversely affect a number of species, including fish, amphibians, and waterfowl, as well as forests and vegetation (see Box 5.3). Sulphur dioxide emissions have also been directly linked to increased respiratory problems in humans. In the past, Canadian smelters emitted large quantities of sulphur dioxide directly into the atmosphere, completely destroying vegetation in some areas (Federal/Provincial Research and Monitoring Coordinating Committee 1990). Although sulphur dioxide emissions from smelters have declined substantially over the past two decades (Table 5.6), a substantial portion of the Boreal Shield ecozone continues to receive elevated levels of acidic deposition; sulphur dioxide emissions have been intensified by other acidifying emissions, such as nitrogen oxides.

Smelter emissions are declining steadily under increasingly strict regulation, voluntary pollution prevention, and competitive pressures to modernize from global market competition, international agreements, and green technology. Recent changes in technologies, plant modernization, and an interest in metal recycling and recovery have combined to decrease the volume of metals emitted into the atmosphere. In some cases, initiatives that are part of the industry's sulphur dioxide reduction strategy also result in reduced metal emissions. Most companies now fully comply with regulatory limits for particulate emissions (Boxes 5.7 and 5.8). In addition, programs such as the Accelerated Reduction/Elimination of Toxics (ARET) program are helping to reduce emissions (see Chapter 11).

Figure 5.8

Mineral regions in the Boreal Shield ecozone, 1990



Source: National Atlas Information Service, Natural Resources Canada

Table 5.5

Area used by mining in Quebec, 1995

Use	Area (ha)
Mine operations and waste	12 235
Storage	0
Infrastructure	150
Total	17 235
Rehabilitated to date	2 043

Source: R. Lemire, Ministère de l'Environnement et de la Faune du Québec, personal communication

Table 5.6

Base metal smelter sulphur dioxide emissions, 1970, 1992, and 1994

Smelter location	Sulphur dioxide emissions (t, 000s)		
	1970	1992	1994
Flin Flon, Man.	265	288	194
Thompson, Man.	485	267	194
Copper Cliff, Ont.	1 992	416	162
Falconbridge, Ont.	342	54	54
Timmins, Ont.	N/A[a]	4	2
Rouyn-Noranda, Que.	619	170	166

[a] N/A= not applicable; smelter opened in 1972

Source: Falconbridge Ltd. (1992); Inco (1993); Noranda Minerals Inc. (1993); Manitoba Environment (1995); data provided by Hudson Bay Mining and Smelting

Box 5.7
Reversing the legacy of Sudbury's sulphur dioxide emissions

Over a century of nickel smelting by Inco and Falconbridge near Sudbury, Ontario, devastated the surrounding landscape and waters. The once-vast forests essentially disappeared. Much of the worst damage was done in the first 50 years, when ore was smelted over huge, open wood fires. Since the 1970s, new processes and the construction of high smokestacks have reduced the total and local impact of the emissions.

Between 1965 and 1985, Inco's Sudbury operations reduced smelter emissions of sulphur dioxide by 70%, recording the largest decrease in emission tonnage among North American smelters. In 1985, the Ontario government unveiled its Countdown Acid Rain Program, which required Inco to increase its containment of sulphur dioxide to 90%. During the 1980s, Inco invested some $530 million on related research and development and developed the necessary new technology. The sulphur dioxide abatement project turned into a wide-ranging facility improvement plan that also generated cost savings for Inco of over $50 million per year and reduced carbon dioxide, nitrogen oxide, and particulate emissions, as well as sulphur dioxide emissions. On 1 January 1994, the company met the government's deadline for reducing sulphur dioxide emissions to a maximum annual level of 265 000 t, setting new standards of environmental stewardship for other companies to follow.

Box 5.8
Technological changes to reduce emissions in Flin Flon

Some Canadian zinc smelters, such as the Hudson Bay Mining and Smelting smelter at Flin Flon, have switched from conventional ore roasting to an advanced hydrometallurgical pressure process. This process leaches toxic metals and sulphur out of wastes in solution. Installation of a new zinc plant brought about significant emission reductions; sulphur dioxide emissions were reduced by capturing up to 98% of the contained sulphur. In addition, the use of Gore-Tex™ fabric materials for filtering purposes has greatly reduced particulate emissions. Mine operators are aiming for particulate emissions as low as 16% of the allowable limit (M. Morelli and D. Bezak, Manitoba Environment, personal communication).

Water

The magnitude and complexity of water pollution problems originating from mining, milling, and further processing vary considerably from site to site. Water pollutants can originate from three key sources: mine dewatering, liquid effluents from the milling process, and surface water drainage and seepage from waste storage areas and inactive mines.

Mine wastes are treated and stored on site. Untreated liquid effluents are normally released to the natural aquatic environment only when they meet strict environmental requirements; however, spills sometimes occur. On a few occasions, spills have been the result of breaches in tailings dams.

Mine and mill effluents containing such metals as cadmium, copper, iron, lead, nickel, and zinc are treated with lime to precipitate the dissolved metals as hydroxides. Liming is usually conducted in settling basins before treated effluents exit the tailings pond. Such treatment generally removes up to 99% of metals and suspended sediments from mine and mill effluent.

Since the early 1970s, metal contamination at many mining sites has decreased, owing to stricter regulatory controls, improved mining and processing practices, and improved technologies. In 1977, the federal Metal Mining Liquid Effluent Regulations and Guidelines came into force to ensure that the most practical and recent technologies are employed to meet regulatory concentration limits. Chapter 11 provides a limited national overview of this issue.

Ontario recently developed effluent monitoring programs and discharge regulations for mine facilities (Stogran 1994). Similar programs have been in place in Quebec for almost 20 years. According to analyses carried out in 1992, 95.7% of companies conform to their standards (J. Roberge, Association Minière du Québec, personal communication).

Acid mine drainage is the most serious problem facing the mining industry in the Boreal Shield ecozone. Acidic pollution of water systems can be caused by mine tailings and waste rock that is naturally high in sulphide minerals. Many mine companies have systems in place that help control and treat acid seepage at both working and abandoned mines. However, controlling acid mine drainage is extremely difficult and remains a major challenge for the mining industry (see Chapter 11).

Mine reclamation

Each year, mines in the Boreal Shield ecozone produce in the order of 100 million tonnes of waste rock. By 1994, more than 1 900 million tonnes of mine waste rock covering almost 5 000 ha were piled at existing and closed mine sites. These sites also contain 3 752 million tonnes of tailings covering an additional 26 483 ha (Table 5.7) (Feasby and Jones 1994).

Since the 1940s, rehabilitation of lands disturbed by mine wastes and facilities has consisted mainly of recontouring and replanting the land to ensure stability, erosion control, and safety. However, these measures have almost no impact on the more critical problem of acid mine drainage and water contamination.

It should be noted that mines are no longer abandoned; instead, they are closed following legislated federal/provincial reclamation procedures. Mines closed and maintained according to these procedures

Table 5.7

Estimates of total accumulated mine wastes and acid mine wastes in the Boreal Shield ecozone, by province, 1994

	Mine waste				Acid mine waste			
	Tailings		Waste rock		Tailings		Waste rock	
Province	t, millions	ha	t, millions	ha	t, millions	ha	t, millions	ha
Newfoundland	608	4 030	605	1 511	30	170	1	1
Quebec	1 177	8 540	1 070	2 720	254	2 390	70	180
Ontario	1 366	9 410	143	357	954	6 130	94	236
Manitoba	209	2 400	102	255	200	1 780	69	172
Saskatchewan	392	2 103	54	136	66	273	20	50
Total	3 752	26 483	1 974	4 979	1 504	10 743	254	639

Source: Feasby and Jones (1994).

have few downstream impacts. The big challenge for long-term containment of mine tailings is ensuring that tailings dams do not fail, as they have on a few occasions (Intergovernmental Working Group on the Mineral Industry 1993).

Radionuclide leakage from mine tailings is an important environmental concern for uranium mines in Ontario and Saskatchewan. Like the products of acid mine drainage, radionuclide wastes need secure, long-term containment to minimize aquatic impact. Water-covered tailings impoundments are one approach now being used at some Elliot Lake sites (Feasby and Jones 1994). At the Rabbit Lake mine in Saskatchewan, tailings are deposited in a mined-out pit with a waterproof lining to prevent seepage to groundwater. Surface runoff waters are pumped away for treatment, preventing infiltration into the tailings. When the mine ceases operations and the tailings are consolidated, a compacted soil cap or water cover will be placed on top of the tailings. The sites are expected to stabilize and not require ongoing maintenance. Similar in-pit tailings facilities have been approved for the McClean Lake and Key Lake mines.

Trends in mine management

The Boreal Shield ecozone supplies a large proportion of Canada's demand for minerals. As the mining heartland of the country, it can serve as a national benchmark against which to measure progress in protecting the environment. As elsewhere, the most visible, "on the ground" impacts of mines are relatively localized. However, mines with sulphide-bearing minerals are prone to acid mine drainage, which poses a potential threat to downstream air and water quality.

Some significant developments have occurred in the past decade to address acid mine drainage and other environmental impacts of mines. For example, in 1988, the mining industry and federal and provincial governments developed the Mine Environment Neutral Drainage (MEND) program under the lead of Natural Resources Canada. MEND is intended to coordinate research and development and to supplement the work initiated by mining companies and research organizations. This $18-million program is funded through a cost-sharing agreement between the industry, the provinces, and the federal government. In addition, technologies to prevent, or substantially reduce, acid mine drainage from waste rock piles, tailings sites, and exposed mine surfaces are being developed and demonstrated in Canada (Natural Resources Canada 1993a). However, the best that can be expected for the tailings and waste rock piles of many existing and orphaned mines is long-term containment and treatment to neutralize acid drainage and remove dissolved metal contaminants (see Chapter 11).

Other important changes have been made by provincial governments. For example, mining companies are now required to provide financial assurances, which may include setting aside funds in trusts or other financial instruments, to ensure rehabilitation of disturbed lands to acceptable standards upon mine closure and decommissioning. Regulatory agencies and the industry are working together to develop appropriate reclamation plans and mechanisms and to ensure that sufficient funding is set aside at the outset of operations to cover eventual reclamation. The industry is also developing a set of guidelines on exploration, design, construction, mining and processing, reclamation and closure, and environmental emergency prevention and response. As well, companies are increasingly incorporating reclamation work in routine mine operations.

The adverse environmental impacts of mining have generally abated over the past decade owing to innovations on several fronts: new regulatory and policy instruments, improved pollution control technologies, more comprehensive provisions for mine decommissioning, and strengthened environmental commitments made by corporate leaders in the field.

Tapping Hydroelectric Resources

Hydro resource base

Canada is the largest producer of hydroelectricity in the world, accounting for 62 722 MW of installed capacity (Natural Resources Canada 1994) and approximately 15% of the world's total production (Energy, Mines and Resources Canada 1987). Thirty-nine percent of Canada's hydroelectric capacity (24 574 MW) (internal water database, Torrie Smith Associates, Ottawa) is located on rivers arising in or flowing through the Boreal Shield ecozone. Of Canada's 662 large dams, 279, or 42%, are located here (internal water database, Torrie Smith Associates, Ottawa). Major developments include those on the Manicouagan, aux Outardes, and Betsiamites rivers in Quebec. Quebec's Ste-Marguerite 3 project is under construction. Other prospective dams for northwestern Ontario are currently on hold.

Diversion projects consolidate water from two or more sources into one trunk line to increase the security and quantity of flow for hydroelectricity. Water diversions in the Boreal Shield ecozone account for 59% of the volume of flow of Canada's major interbasin water diversions (Day and Quinn 1992). The volume of water diverted in Canada is the greatest in the world (Day and Quinn 1992). Within the Boreal Shield ecozone, a total of 2 612 m^3/s are diverted, constituting 60% of the total water diverted in Canada (Day and Quinn 1992).

The majority of the drainage basins contained in whole or in part in the Boreal Shield ecozone have been altered by hydroelectric development in one way or another. Table 5.8 details the rivers and drainage areas affected in this ecozone. The power created from falling water, diverted or not, is moved via transmission lines generally from north to south.

Hydroelectric development resulted in the creation of several one-industry towns, including Thompson, Manitoba; Terrace Bay, Ontario; Arvida, Quebec; and Corner Brook, Newfoundland. Fifty percent of Ontario's electricity-intensive industries are located in this ecozone, accounting for approximately 25% of the province's industrial electricity consumption (internal water database, Torrie Smith Associates, Ottawa).

Table 5.8
Watersheds restructured for hydroelectric development

Watersheds	Dams	Reservoirs	River diversion
Churchill and Naskaupi rivers	X	X	X
Newfoundland (insular) rivers	X	X	
Manicouagan and aux Outardes rivers	X	X	
Betsiamites River	X	X	
Saguenay River	X	X	
Middle North Shore, near Quebec City	X		
St. Maurice River	X	X	
Eastern Laurentian rivers	X	X	
Lower Ottawa River	X	X	
Upper Ottawa River	X	X	
Trent River	X	X	
Georgian Bay shore rivers	X		
North Huron shore rivers	X	X	
Lake Superior shore rivers	X	X	X
Moose River	X		X
Albany River			X
Saskatchewan River	X	X	X
Churchill River	X	X	X
Nelson River	X	X	X
Winnipeg River	X	X	X

Source: Statistics Canada (1986); Woo and Waylen (1987); internal water database, Torrie Smith Associates, Ottawa.

Box 5.9
Community-based planning at Split Lake

In Manitoba, the provincial utility and First Nations are now working more closely on projects within the First Nations' traditional lands. When a transmission line was constructed into the community of Split Lake in the early 1990s, the community had input into planning the project, the community was the main contractor with a joint venture partner, and community members represented 78% of the workforce and worked 65% of the total person-hours. Manitoba Hydro is using the Split Lake experience as a model for future development, including the routing of transmission lines into seven other remote communities. Each undertaking would involve early environmental studies for future hydroelectrical generation development.

Development impacts

Land

Besides the obvious loss of terrestrial habitats through dam construction and reservoir impoundment, other land-based impacts of hydro projects relate to soil erosion and transmission corridors.

Shoreline erosion and scouring of river channels are common results of hydroelectric developments in the Boreal Shield ecozone. The amount of erosion and soil loss that takes place varies widely with soil type, the relative amount of area flooded, and the range of fluctuations in water levels (see Chapter 8). Another important impact has been the destruction of riparian vegetation. This has affected the landscape, as riparian areas along rivers and lakes are often the

only places where deciduous trees can grow in this largely coniferous ecozone.

Transmission lines from hydroelectric installations travel inside clear-cut corridors through forests and wetlands. Their presence can reduce the wilderness character of remote regions, cutting long, wide swaths through otherwise undisturbed terrain (Box 5.9). Evidence from the Upper Salmon River area in Newfoundland suggests that increased hunting access provided by transmission corridors may be linked to local depletions of wildlife (Goudie 1990). In addition, many corridors are treated with chemical herbicides, which may have localized impacts on the food chain.

Water

Foremost among the impacts of hydro dam construction, river diversions, and flooding are those on aquatic fauna: species are displaced, food chains are restructured, and mercury contamination increases (Environment Canada 1987) (Box 5.10).

Aquatic ecosystems are affected by hydroelectric development in several ways. For example, increases in water volume caused by the flooding of river valleys and the creation of reservoirs often disperse existing species, resulting in altered competitive and predatory regimes. Lake Trout may exhibit recruitment problems in reservoirs. Reservoir impoundment interferes with the normal homing behaviour of the species, and spawning fish can show little inclination to find new spawning sites in more suitable sectors. Moreover, winter drawdown probably limits the survival of embryos and alevins, because eggs are usually deposited in relatively shallow water (Deslandes et al. 1995). Brook Trout is another species adversely affected by impoundments.

The flooding of organic matter by reservoirs results in the methylation of naturally occurring inorganic mercury, which may then be toxic at elevated levels. This methylmercury can subsequently be incorporated into both aquatic and terrestrial food chains (see also Chapter 8).

Box 5.10
Mercury, fish, and dams

Following the construction of new dams, elevated levels of methylmercury are produced by the rotting of submerged vegetation. However, recent studies suggest that elevated mercury levels in fish are transitory. Only a very small portion of the flooded organic material is readily decomposable, and this fraction is degraded within 5–10 years of impoundment (Van Coillie et al. 1983; Thérien 1990; Schetagne 1994). Thus, the increased production of bioavailable methylmercury lasts only for a relatively short time.

Data from reservoirs located on glacial till in Quebec and Labrador, flooded 5–65 years ago, suggest that mercury concentrations in whitefish and pike would reach background levels 20–30 years after impoundment (Verdon et al. 1991). Another study found a high correlation between mercury levels in 1-kg Northern Pike and the age of reservoirs in Finland (Verta et al. 1986); this research indicated that mercury levels would reach natural values 15–20 years after filling of the reservoir.

More recent data for reservoirs in the Churchill–Nelson complex in northern Manitoba, where pre- and postimpoundment levels are available, show that levels of mercury in Lake Whitefish peaked 3–5 years after flooding and returned to preimpoundment levels 10–20 years after flooding (Strange 1995). Mercury levels in pike and Walleye peaked after 4–10 years and declined gradually between 6 and 20 years after flooding. Data from reservoirs of the La Grande complex in Quebec show that mercury levels in non-fish-eating fish species peaked 4–5 years after flooding and declined by half 15 years after flooding (Doyon et al. 1996). For the same reservoirs, concentrations in fish-eating species (Northern Pike and Walleye) peaked 8–13 years after flooding and began to decline significantly 14–15 years after flooding.

Some observers argue that long-range atmospheric transport of mercury has contributed to the total mercury concentrations in reservoirs. Fish and water containing elevated mercury levels are not found only in reservoirs. For instance, throughout the Quebec portion of the Boreal Shield ecozone, average-sized individuals of species such as Northern Pike, Walleye, and Lake Trout (all fish-eating species) have mercury levels that exceed Canadian marketing standards of 0.5 ppm (Verdon et al. 1991). Moreover, some researchers suggest that mercury concentrations in lake sediments in the Quebec portion of the Boreal Shield ecozone may be 2–3 times higher than preindustrial concentrations (Lucotte et al. 1995).

Other experts, however, point to the complexities involved in interpreting mercury distributions in lake sediment columns: mercury distribution in these sediments is influenced by physical, chemical, and biological events that occur after the mercury is deposited. This makes it difficult to assess the relative contribution of long-range atmospheric inputs compared with geologically controlled inputs and processes (Rasmussen 1994; Coker 1995). Research conducted under the Canada–Manitoba agreement on the Churchill River diversion (Manitoba Environment and Workplace Safety and Health 1987) concluded that mercury in the impounded area comes from natural sources, with the bedrock being the ultimate source — a conclusion later echoed by the International Programme on Chemical Safety (1989).

Many of the impacts of reservoir construction, particularly the dynamics of mercury release, are as yet poorly understood. Long-term studies are being conducted in the Churchill and Nelson river areas to determine whether mercury levels in fish decline as a reservoir ages (Jones et al. 1986). These studies show that continued erosion and sediment loading may perpetuate the conditions for sustained higher levels of mercury in fish.

Certain areas of the Boreal Shield ecozone appear more susceptible to mercury prob-

lems. Reservoirs in northern Manitoba, northern Ontario, and Labrador generally show higher mercury levels than those in Nova Scotia, New Brunswick, southern Manitoba, and British Columbia (Jones et al. 1986) (see Chapter 8).

Controlling water releases from hydro dams and reservoirs to protect the downstream environment is becoming common practice at several Boreal Shield ecozone hydro projects, including the Cabonga Hydro Reservoir (Quebec), Bark Lake Dam on the Madawaska River (Ontario), and Red Rock Falls on the Mississauga River (Ontario). Several provincial governments have enacted regulations specifying water release targets for fish protection, and the federal government monitors salmon habitat and the water release rate (Hill 1984).

Loons, which nest at the water's edge because of their restricted mobility on land, are affected by the changing water levels in reservoirs. Studies have shown decreased reproduction levels (Croskery 1990). However, the birds appear to reproduce successfully on artificial platforms constructed as nesting sites around the reservoir shorelines (Bildfell 1992).

Ombabika Bay, Lake Nipigon, is the receiving water body for the Little Jackfish River, which carries water diverted from the Ogoki River. This diversion increased maximum and average water flow in the Little Jackfish River by 8 and 30 times, respectively. Since 1943, when the diversion was constructed, these flow alterations have caused the erosion of 90 million cubic metres of sediment from the river, increasing turbidity, siltation, and sedimentation in Ombabika Bay (Box 5.11).

Impacts on Aboriginal peoples

The effects of hydroelectric development have been particularly significant for Aboriginal peoples because of their patterns of settlement along the shores of rivers and lakes. Ironically, some Aboriginal communities that were relocated to permit the building of hydroelectric dams and reservoirs have had to wait years for access to the power generated by these facilities. Some Boreal Shield ecozone Aboriginal communities — for example, the Whitedog community in Ontario — depend on diesel generators for electricity, although major hydroelectric installations are close by. In the 1950s, diversion of the Albany River caused hardship for Aboriginal peoples who depended on local fish stocks in Osnaburgh in northern Ontario.

Trends in hydro project management

Many of the large-scale hydro projects in the Boreal Shield ecozone may be approaching the end of their productive lives. Half the dams are at least 40 years old. Two-thirds of Ontario's dams are over 50 years old. Because of their age, none of these dams is subject to environmental study by Ontario Hydro (Ontario Hydro 1991). Only if a facility is being redeveloped (e.g., Mattagami, Ontario) are routine environmental studies conducted. No new dams have been built in Ontario since 1982 (Canadian National Committee of the International Commission on Large Dams 1991).

Increasing numbers of facilities will require major overhauls in coming years (Ontario Hydro 1988). The long-term maintenance and reclamation of aging dams are emerging environmental concerns that have yet to receive significant study or policy attention from provincial governments.

There is some concern that future facilities may be developed that are of little value locally but of great value to electricity consumers in other provinces or the United States (National Energy Board 1994). Meanwhile, Newfoundland is exploring the feasibility of small-scale run-of-the-river plants to meet local needs.

Aboriginal people are assuming a growing role in resource and environmental management. For example, an agreement was signed between Hydro-Québec and the Montagnais community (Uashat Mak Mani-Utenam) to collaborate on implementing measures to mitigate environmental impact and compensate those affected by the development of the Ste-Marguerite 3 hydroelectric project. The Manitoba Northern Flood Agreement is another example of a mitigation settlement between hydroelectric developers and Aboriginal peoples.

The bulk of hydroelectric development in this ecozone is likely over, and ongoing initiatives such as regulated streamflows and community-based project planning demonstrate promising commitments to environmental protection. However, many environmental questions surround the history of large-scale hydro projects in the Boreal Shield ecozone. Until provincial hydro utilities and governments give greater priority to ecosystem monitoring, hindsight assessments, and baseline research, many of these questions will go unanswered, and their potential value to future projects both here and in other regions may be lost.

Box 5.11
Effects of diversion-induced erosion on the fish of Ombabika Bay, Lake Nipigon

The immense sediment loads entering Ombabika Bay — 3 million cubic metres annually — contributed to marked changes in fish habitat and species composition. Increased turbidity provided a competitive advantage to Sauger, a fish species better adapted to dim light conditions than Walleye, which were much more plentiful before the diversion project. Commercial exploitation may be a contributing factor to this shift in community structure.

Diversion-induced erosion from the Little Jackfish River has also contributed to increased methylmercury contamination of fish in Ombabika Bay. Consumption restrictions remain in effect for Sauger but have been lifted for most other species owing to a recent decline in mercury concentrations (R. Salmon, Ontario Ministry of Natural Resources, personal communication).

The Road to Sustainable Development

Over many decades, the supply of natural resources from the Boreal Shield ecozone has affected its air, water, forests, and landscape. At local and regional scales, forestry activities, mining, and hydroelectric developments continue to cause disturbances and impacts on the landscape.

Although the direct measurable footprint of human activities remains comparatively small in this ecozone, the nature of many industrial developments presents an ongoing challenge for realizing sustainable development. Innovative, integrated resource management practices incorporating the principles of sustainable development and an ecosystem approach will help sustain the Boreal Shield ecozone's natural processes and diversity for the benefit of future generations.

Today, the overall trend in the ecozone is probably towards greater sustainability owing to changes in regulations and standards, corporate practices, and public and professional attitudes and goals, plus the gradual evolution of management practices. Quantitative methods to assess whether ecosystems are functioning in a relatively natural and productive state have yet to be developed. The long-term opportunity — and challenge — is to develop and apply measurements that objectively assess and measure basic environmental characteristics that are to be maintained for the benefit of future generations.

There are many trends in planning and managing natural resources that suggest that Canadians can be optimistic about progress being made towards sustainability in the Boreal Shield ecozone. For example, public participation is an increasingly important dimension of resource management. This process has become particularly important to the people living in the ecozone, because they are the ones who see most clearly the impact of development on the quality of local ecosystems and lifestyles. There is also a recognition that local-scale decisions must be made in the context of the larger national and global view. Economic issues and assessments remain driving forces in resource development policies across the country, but other factors are of growing importance.

High on the list of accomplishments are the substantial reductions in toxic discharges — particularly in air emissions of sulphur dioxide, nitrogen oxides, and particulates — achieved by many mining and smelting operations. These improvements come from a combination of advanced technologies, progressive regulations, and enhanced corporate stewardship.

Simultaneously, there has been progress in the area of mine closures. Both industry practices and government regulations reflect increased recognition of the need for proper mine site decommissioning.

Saskatchewan, Manitoba, Quebec, Ontario, and Newfoundland have embraced the concept of integrated forest management by requiring plans to be established prior to any harvesting. A key feature of integrated forest management is that it addresses the sustainability of forests and wood supply and of the natural resources of water and soils, while accounting for wildlife, tourism, and aesthetic values.

The need for better information and data to support sustainable development is increasingly recognized. Generally agreed upon techniques for measuring biodiversity and monitoring environmental change have yet to emerge, but recent progress in this area has been made (Box 5.12).

Linked to growing concern for biodiversity and ecosystems is renewed interest in creating new protected areas and better managing existing ones. Six new provincial parks in this ecozone are proposed in Quebec's Provincial Parks Action Plan (1992–1997): Rivière Vauréal, Mont Valin, Monts Otish, Lac Albanel et Rivière Témiscamie, Aguanus-Kenamu morainic complex, and Harrington Harbour. Manitoba designated Amisk Provincial Park, which is located in the northern portion of the Boreal Shield ecozone, in early 1995. Ontario is committed to expanding Wabakimi Provincial Park to almost 900 000 ha (Valpy 1995).

Box 5.12
Ecosystem monitoring and assessing ecozone sustainability

Since the early 1990s, research on ecological assessment and monitoring has been carried out by Environment Canada. In April 1994, the department established the Ecological Monitoring and Assessment Network (EMAN) to facilitate cooperation among scientists, governments, and universities and to promote a holistic approach to ecological inquiry and ecosystem understanding.

The EMAN is a network of Ecological Science Cooperatives (ESCs) now being established at sites across Canada in every ecozone. Each ESC is composed of cooperative sites where scientific research and monitoring activities are jointly planned and conducted and results integrated. To accommodate both the large expanse and diversity of the Boreal Shield ecozone and to address the administrative complexities across multiple jurisdictions, a series of sites has been established in the ecozone: one on the Avalon Peninsula, Newfoundland; Duchesnay on the Lac Clair basin, Quebec; Charlevoix Biosphere Reserve, Quebec; Montmorency Forest, Quebec; Lac Duparquet's teaching and research forest, Quebec; La Mauricie National Park, Quebec; the Laurentides St-Hippolyte biological station, Quebec; Coldwater experimental watersheds, Ontario; Experimental Lakes Area, Ontario; Pukaskwa National Park, Ontario; Sudbury Industrial Barrens, Ontario; and Turkey Lakes Watershed, Ontario. Work is under way to confirm sites in the Manitoba, Saskatchewan, and western Newfoundland and Labrador portions of the Boreal Shield ecozone.

By encouraging cooperative ventures among scientists across many disciplines, the EMAN aims to promote better understanding of ecological processes and to begin to supply answers on sustainability within ecozones.

The appropriate balancing of land uses in the Boreal Shield ecozone is the subject of continuing debate, involving details of management practices as well as fundamental values. In some situations, land use decisions will entail excluding portions of land from certain types of resource use; in other instances, lands may be assigned exclusively to special designations. In all cases, land use decisions must contend with the need to tap the full range of economic benefits of the land while respecting other social and environmental goals.

Many see protected areas not only as crucial for ecological research, as baselines for long-term monitoring, and as key reserves of biodiversity, but also as anchors for tourism and recreational activities. The federal government has pledged to set aside areas representative of Canada's ecosystems, setting a target of 12% (Senate of Canada 1996) (see also the "Protected areas" section of Chapter 14). As Table 5.4 shows, 7.4% of the total ecozone now enjoys some level of protection, up from 3.0% in 1960.

Another key indicator of progress is the move towards comanaging resources with Aboriginal groups, particularly in Manitoba and Saskatchewan. This process is important both for recognizing Aboriginal peoples' concerns as well as for integrating local knowledge and goals into resource management decisions. Although currently applied mainly to wildlife resources, it could have much larger application both within and outside Aboriginal communities.

Finally, the development of regular state of the environment reporting programs in Manitoba, Saskatchewan, Quebec, and the Atlantic region points to heightened provincial commitments to reporting on environmental management. Such processes will test the quality of baseline environmental information required to achieve successful reporting. Another promising data-gathering initiative adopted by these jurisdictions, plus Ontario, is the move towards a more ecosystem-based approach to forest inventories. These will incorporate climatic, soil, and wildlife data along with conventional timber data.

The mining, forestry, and hydro generation carried out in the Boreal Shield ecozone make a major contribution to the Canadian economy. The challenge is to carry out these activities in a sustainable manner, ensuring that economic uses do not jeopardize other uses of this ecozone — as wildlife habitat, as a place for traditional subsistence and cultural activities, and as a wilderness that many Canadians come to enjoy. Despite shrinking budgets and pressures to do more with less, there are promising signs of new and more sustainable approaches to resource management in the Boreal Shield ecozone. In short, there is room for cautious optimism. The resources of this landscape of rock, forests, and lakes are important for more than the direct and immediate economic opportunities they afford.

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Chapter 6 Great Lakes–St. Lawrence Basin

Highlights

The Great Lakes–St. Lawrence basin stretches from the western edge of the Lake Superior drainage basin to the St. Lawrence estuary. Some 8.5 million Canadians live in the Great Lakes portion of the basin, most of them along the shores of the lakes, and another 7 million live along the St. Lawrence River and estuary.

■

The Mixedwood Plains ecozone portion of the basin represents only 9% of Canada's land area but is responsible for 37% of Canada's agricultural production. The intensive agricultural production is linked to such problems as soil erosion, eutrophication of surface waters, and nitrate and bacterial contamination of rural well water. The problem of pesticide contamination has declined substantially, partly owing to programs to reduce pesticide use. Tilling practices have been improving in recent years — over 50% of farms now apply crop rotation or winter cover crops such as winter wheat, and almost 20% practise conservation tillage or zero tillage.

■

Expanding urbanization around Toronto and Montreal — Canada's two largest metropolitan centres — and other cities is leading to the disappearance of prime agricultural lands, the loss or degradation of natural areas, and pollution linked to increasing use of automobiles. Largely because of automobiles, the Windsor–Quebec City corridor has the highest smog pollution in the country, which has been strongly linked to increases in respiratory illnesses.

■

Dredging and dams in the St. Lawrence River (e.g., the Moses–Saunders and Beauharnois dams) have changed the current in the river, modified habitats, and obstructed the migration of American Eel, sturgeon, and other fish species. Upstream of the Beauharnois power station, 84% of the flow of the St. Lawrence River has been diverted from its natural channel (the Soulanges Rapids) into the Beauharnois Canal. Continuing dredging in the St. Lawrence and the connecting channels of the Great Lakes system disturbs bottom habitat and contributes to the resuspension of persistent toxic chemicals buried in sediments. Waves from ships using the St. Lawrence Seaway are eroding shorelines at some locations at the rate of 4.5 m per year.

■

Important indigenous fish populations collapsed (e.g., Lake Whitefish and Lake Herring) or were extirpated (e.g., Lake Trout) in most of the Great Lakes by the early 1960s. Overfishing and Sea Lamprey predation are thought to have been the main causes. Vigorous Sea Lamprey controls, a large stocking program, and catch limitations have brought Lake Trout back to the lakes, have introduced other, nonindigenous salmonids (Coho Salmon, Chinook Salmon, and Brown Trout), and have brought a dramatic resurgence of Lake Whitefish and, to a lesser degree, Lake Herring in the lakes. In all but Lake Superior, however, the survival of Lake Trout populations depends upon stocking programs. Interactions with nonindigenous species (e.g., Alewife), limited spawning habitat, and loss of genetic variability appear to hinder their reproduction. Persistent toxic chemicals may also play a role.

■

The St. Lawrence Seaway and the vessels that use it are major routes for the entry of exotic species into and their spread throughout the Great Lakes–St. Lawrence system. Since 1810, 139 aquatic species have been introduced into the Great Lakes, roughly one-third of which have arrived since the St. Lawrence Seaway was opened in 1959. Shipping activities accounted for nearly 30% of the introductions.

■

Principal threats to terrestrial biodiversity in the basin include the loss of wetlands and other critical habitats to agricultural development and urbanization and competition from introduced species. As of April 1995, the Committee on the Status of Endangered Wildlife in Canada listed 27 species, subspecies, and populations in the Mixedwood Plains ecozone as endangered; 32 more were listed as threatened.

■

Annual phosphorus inputs to the Great Lakes have been reduced to the amounts foreseen by the Great Lakes Water Quality Agreement. As a result, eutrophication has largely disappeared from the open lakes and is now mostly confined to some 18 Areas of Concern in the Great Lakes and some tributaries of the St. Lawrence. The reduced nutrient levels are combining with the impacts of the Zebra Mussel to bring about changes in the aquatic community structure and the productivity of the lakes. For example, Alewife, Rainbow Smelt, Yellow Perch, and some other species are decreasing, whereas bottom-feeding fish and those preferring clearer water are increasing.

■

Releases into the St. Lawrence from 50 priority industrial plants in Quebec have been reduced by almost 75% since 1988; releases of polychlorinated biphenyls (PCBs) and mercury from the Cornwall–Massena Area of Concern have also been greatly (over 90%) reduced. The reduction in direct emissions of persistent toxic substances to the Great Lakes and the St. Lawrence is reflected in the lower levels of these substances in fish and the eggs of fish-eating birds. Some contaminated sediments are also being removed, and one of the Areas of Concern in the Great Lakes (Collingwood Harbour) has been restored. Birth defects and reproductive failures in fish-eating species have decreased considerably from the numbers reported in the 1970s, and wildlife populations are recovering. The levels of PCBs and dichlorodiphenyltrichloroethane (DDT) in human breast milk of mothers in Quebec and Ontario have also decreased considerably.

■

Since about 1985, declines in the levels of persistent toxic chemicals in fish and fish-eating birds have slowed down or stopped. Atmospheric deposition of toxic substances is now recognized as a major input of new contaminants to the lakes, and some of these substances come from sources far from the Great Lakes–St. Lawrence basin. Advisories to limit the consumption of certain species of fish remain in effect in many locations.

■

Climate change is expected to lead to lower water levels and lower flow for all Great Lakes and the St. Lawrence River, an increased frequency of drought (particularly in the southwestern portion of the Lake Erie basin), a decrease in groundwater and surface water supplies, changes in aquatic and wetland habitats, changes in fish communities, and increased smog.

■

In the Lake Superior basin, the Peregrine Falcon has been reintroduced after being extirpated, and at least five breeding pairs have fledged young birds. The Woodland Caribou now numbers only a few hundred and is mostly limited to protected areas. Thanks to Sea Lamprey control and stocking programs, Lake Trout have returned to historic levels in some areas. Lake Superior has been chosen as a demonstration project for the zero discharge of persistent toxic substances, a program supported by all jurisdictions in the Lake Superior basin in a binational program, coordinated by the Lake Superior Binational Forum. Currently, toxic contaminants in the lake come primarily from the air.

■

The Carolinian ecosystem of the Lake Erie basin, which has the most southern characteristics and the most indigenous species of all the ecosystems of Canada, has been extensively modified by agriculture and urbanization. Remaining forest cover ranges from only 3% to 16% in fragmented plots, and 50% of all land is now cropland. Lake Erie is the most productive of all the Great Lakes; however, it is currently undergoing major changes in productivity and its biotic communities, mostly in response to lower nutrient inputs and the invasion of the Zebra Mussel.

■

The Lake Ontario basin contains the largest metropolitan complex in Canada. Some of the degraded rivers (e.g., Rouge, Don, and Humber) are being rehabilitated, largely by citizen initiatives. Lake Ontario has one of the largest stocking programs of trout and salmon in the Great Lakes, although the number of stocked top predator fish has now been reduced by about one-third from its high of 8.5 million hatchery-reared fish stocked in 1988.

■

Between 1970 and 1990, the area devoted to grain corn in the St. Lawrence Lowlands ecoregion increased almost fivefold, and the amounts of nitrogen fertilizer and pesticides used increased threefold.

■

From a survey of St. Lawrence Belugas in 1995, a population index of 705 ± 108 was estimated. The method used to count the Belugas tends to underestimate the number of individuals diving during the count. Thus, the actual population may be larger than the numbers indicate. Recent surveys have indicated that the Beluga population of the St. Lawrence may be slowly increasing (by about 3% per year on average).

■

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Setting the Stage

Geographical context

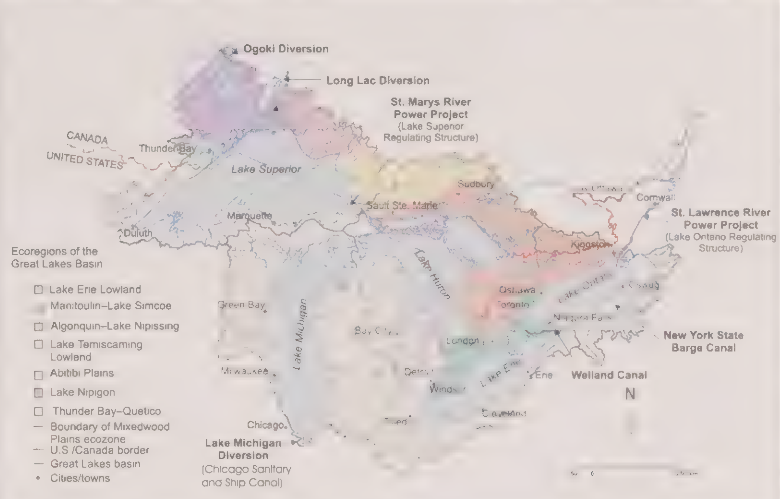
The Great Lakes–St. Lawrence basin stretches from the western edge of the Lake Superior drainage basin to the Gulf of St. Lawrence (Fig. 6.1a, b). The southern part of the basin — the lower Great Lakes and St. Lawrence Lowlands ecoregion, or Mixedwood Plains ecozone — is one of the largest urban and industrial hubs of North America, whereas the sparsely populated northern areas can be viewed as a huge, resource-rich "hinterland." An unending flow of water links the relatively pristine hinterland to the urban and industrial powerhouse of the lowlands. Along the way, environmental stresses increase in both variety and magnitude, transforming the natural environment.

This chapter is organized on the premise that large systems (e.g., the ecosystem of the Great Lakes–St. Lawrence basin or the Mixedwood Plains ecozone as a whole) function as a set of diverse systems nested inside one another (e.g., the ecosystems of individual lakes or lake drainage basins or of ecoregions, the subunits of ecozones). Lower-level systems, such as a woodlot, open field, or shoreline wetland, function as individual ecosystems and at the same time are part of a larger and more complex system (e.g., the lake on whose shore the wetland has developed). Different types of lower-level systems provide the diversity that is a prerequisite for the functioning of any complex system (Holling 1995).

The chapter is divided into four parts. The first part provides a general introduction to the Great Lakes–St. Lawrence basin. The second and third parts together describe how society has interacted with the environment in this basin and the resulting impacts. To do this, the second part discusses issues of concern across the entire basin, such as issues related to agriculture, biodiversity, and persistent toxic contaminants. The third part then provides examples of five distinctive lower-level ecosystems: the hinterland (the Lake Superior basin); an ecosystem radically transformed by agriculture (the Lake Erie basin); an ecosystem strongly influenced

Figure 6.1a

Map of the Great Lakes basin, with its subbasins, diversions, lake regulating structures, and ecoregions



Source: Prepared by the Water Issues Division, Environment Canada, Ontario Region, for the State of the Environment Directorate. Ecoregion boundaries from Ecological Stratification Working Group (1996)

Figure 6.1b

Ecozones of the St. Lawrence basin

Source: State of the Environment Directorate, Environment Canada

Figure 6.1c

Areas, populations, and population changes in the Great Lakes basin, the St. Lawrence basin, and the Mixedwood Plains ecozone

	Area of basin, lake, or ecozone (km^2)				Population			Proportion of urban to total population (%)	
	Land (Canada)	Land (U.S.)	Lake surface	Total	United States (1990)	Canada (1991)	% change, 1971–1991, Canada	Canada (1971)	Canada (1991)
Lake Superior, lake and basin	83 106	44 594	82 100	209 800	425 548	181 573	6	86.4	77.7
Lake Michigan, lake and basin		118 000	57 800	175 800	10 057 026				
Lake Huron, lake and basin	90 551	43 549	59 600	193 700	1 502 687	1 191 467	32	60.0	61.5
Lake Erie, lake and basin	22 944	55 056	25 700	103 700	10 017 530	1 858 171	22	74.6	78.8
Lake Ontario, lake and basin	28 709	35 321	18 960	82 990	2 704 284	5 446 611	37	92.9	90.3
All of Great Lakes basin	225 310	296 520	244 160	765 990	24 707 075	8 677 822	32	84.0	83.6
St. Lawrence basin (Ontario)	107 980					1 217 513	30	74.3	73.3
St. Lawrence basin (Quebec)	652 354					6 644 944	15	82.1	79.1
All of St. Lawrence basin (Canada)	760 334					7 862 457	17	81.0	78.2
Great Lakes and St. Lawrence basins	985 644					16 540 279	24.5	82.5	81.0
Mixedwood Plains ecozone	111 192			168 142		14 016 101	27	86.1	84.8

Source: Statistics Canada (1994b) (Canadian basin areas and population); Environment Canada and U.S. Environmental Protection Agency (1995b) (lake areas, U.S. land areas and populations); Agriculture and Agri-Food Canada, ecological classification project (ecozone areas); 1991 Census as compiled by Statistics Canada for the State of the Environment Directorate, Environment Canada (ecozone populations).

by urban development (the Lake Ontario basin); a region where urban development, industrialization, intensive agriculture, and a defining water body are combined in a narrow space (the St. Lawrence Lowlands ecoregion); and a highly diverse aquatic ecosystem (the St. Lawrence estuary). Finally, the chapter offers some conclusions and discusses ways to work towards the long-term sustainability of the system.

Spatial frameworks used in the chapter

Environmental management in the Great Lakes–St. Lawrence basin has long been structured according to the drainage basin boundaries of the large bodies of water. For example, binational treaties and agreements have been concluded for the area within the boundaries of the Great Lakes basin, and a wealth of environmental information, organized by drainage basins, has accumulated over the years. Thus, whereas the other ecozone chapters are organized according to

Figure 6.1d

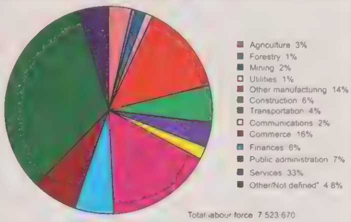
Population change in selected centres in the Great Lakes–St. Lawrence basin, 1971–1991

		Population		
Selected centres	Ecozone	1971	1991	% change
Toronto, Ont.	Mixedwood Plains	2 628 043	3 893 046	48
Montreal, Que.	Mixedwood Plains	2 743 208	3 127 242	14
Ottawa–Hull, Ont.–Que.	Mixedwood Plains	602 510	920 857	53
Quebec City, Que.	Mixedwood Plains	480 502	645 550	34
Hamilton, Ont.	Mixedwood Plains	498 523	599 760	20
London, Ont.	Mixedwood Plains	286 011	381 522	33
Kitchener–Waterloo, Ont.	Mixedwood Plains	254 035	377 762	49
St. Catharines–Niagara Falls, Ont.	Mixedwood Plains	303 429	364 552	20
Windsor, Ont.	Mixedwood Plains	258 643	262 075	1
Oshawa, Ont.	Mixedwood Plains	120 318	240 104	100
Chicoutimi–Jonquière, Que.	Boreal Shield	133 703	160 928	20
Sudbury, Ont.	Mixedwood Plains	155 424	157 613	1
Sherbrooke, Que.	Atlantic Maritime	84 570	139 194	–
Trois-Rivières, Que.	Mixedwood Plains	97 930	136 303	–
Thunder Bay, Ont.	Boreal Shield	112 093	124 427	11
Sault Ste. Marie, Ont.	Boreal Shield	80 332	81 476	1

Note: The population of the Census Metropolitan Area (population over 100 000) was selected where applicable; where the population changed from under 100 000 in 1971 to over 100 000 in 1991 (Sherbrooke, Trois-Rivières), the areas and their populations may not be directly comparable.

Source: Statistics Canada (1994b) and special tabulation prepared by Statistics Canada based on the 1971 and 1991 censuses of population. For further details, see Endnotes.

Figure 6.1e
Labour force composition in the Mixedwood Plains ecozone, 1991

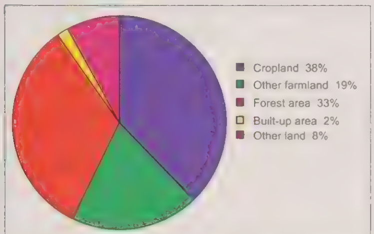


Note Using the 1970 Standard Industrial Classification, the four primary sectors have been grouped with their respective first-stage resource processing industries. For further details, see Endnotes.

* "Other/Not defined" represents labour force categories that were less than 0.5% of the total labour force as well as responses for which the respondent did not specify the industrial category in which he/she or other household members were employed.

Source Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada.

Figure 6.1f
Land cover distribution of the Mixedwood Plains ecozone



Notes 1 The resolution provided by AVHRR (Advanced Very High Resolution Radiometry) is insufficient to provide adequate information on area and land cover distribution in the Mixedwood Plains ecozone. Therefore, data from the Agricultural Census of Canada and Canada's Forest Inventory were used for the figure. AVHRR data were used for "built-up area." AVHRR data are listed here for comparison with the other chapters: agricultural cropland 72%, deciduous forest 4%, mixedwood forest 22%, total land area 101 362 km².

2 Farm woodlots may have been counted twice: once as "other farmland," once as "forest area."

Definitions 1 "Other farmland": land owned or leased by farm operators but not under crops; includes summerfallow, pasture, farm woodlots, wetlands, and other land not under crop.

2 "Other land": all land not in the other categories (vegetated land that is neither forested nor farmland, barren land, etc.); may also partially reflect errors of approximation.

Source Canada's Forest Inventory (Lowe et al. 1996), Agricultural Census of Canada 1991, as aggregated within the boundaries (ecodistricts) of the ecological classification project of Agriculture and Agri-Food Canada and the State of the Environment Directorate, Environment Canada.

the ecological land classification system (see the Introduction to Part II of this report), this chapter uses primarily the drainage basin classifications.

Ecological land units are based on similarities in soils, topography, vegetation, and climate. Drainage basins are defined by topographic boundaries that determine water flows into a water body. Both classification systems are hierarchical, fitting smaller units (ecoregions and subbasins) into larger ones (ecozones and drainage basins), and each has its own advantages. For a discussion of a topic relevant to an aquatic ecosystem, such as toxic chemicals or exotic species, the drainage basin classification system is more useful, because it explains the movements of chemicals and organisms within the hydrologic cycle. However, the ecological classification system is more appropriate in the analysis of terrestrial flora and fauna and of productivity of agriculture and forestry. Ecozones are increasingly being used in Canada, the United States, and Mexico (ecozone boundaries are consistent across the three countries) to evaluate biodiversity, habitat, and the productivity of renewable resources.

Putting the two classification systems together, the combined Great Lakes–St. Lawrence basin includes all of the Mixedwood Plains ecozone, which reaches from Windsor in the west to just beyond Quebec City in the east, and part of the Boreal Shield ecozone to the north.

Land and water

The land in the basin has been shaped by the repeated advances and retreats of continental ice sheets, which gouged out deep trenches in the relatively soft sedimentary bedrock on the edge of the Canadian Shield. The last glacier to cover the region, the Wisconsin, melted about 11 000 years ago. The meltwaters pooled into the precursors of the present lakes and drained south into the Mississippi basin and southeast into the Atlantic Ocean. The Champlain Sea covered the St. Lawrence and lower Ottawa valleys until about 9 800 years ago. The Great Lakes in their present form, draining through the St. Lawrence River, appeared about 2 000–3 000 years ago (Francis and Regier 1995).

In the north, the glaciers scoured the ancient granitic bedrock of the Canadian Shield, leaving large expanses exposed. To the south, the glaciers deposited silt, sand, and gravel, forming tills. Moraines, such as the Oak Ridges Moraine near Toronto, form some of the most prominent reliefs in the otherwise level to rolling landscape. The Niagara Escarpment, which extends northwest from Niagara Falls to Georgian Bay, and the Monteregian Hills around Montreal form the only other reliefs. In the east, glacial meltwater lakes and the Champlain Sea left deposits of clay and silt, forming today's outwash plains and kettle lakes. All these deposits provided the basis of the fertile soils of the Mixedwood Plains ecozone. Soils in the northern portions of the basin are shallow, often acidic, and generally much less fertile.

The Great Lakes, with about 20% of the world's fresh surface water, together make up the largest freshwater lake system in the world (Fig. 6.1h). The combined drainage area of all the lakes is 766 000 km², 32% of which is water. Average depths of the Great Lakes range from 19 m for Lake Erie to 147 m for Lake Superior (Fig. 6.1h). Their combined volume is 23 000 km³ — an amount of water that would be sufficient to keep the St. Lawrence River flowing for 100 years. Retention times (the time required to exchange all the water) range from 2.6 years for Lake Erie to 191 years for Lake Superior (Fig. 6.1h). The lakes are not large enough to have noticeable tides, but winds blowing the length of a lake sometimes cause water levels to differ by more than 2 m from one end of the lake to the other. Such phenomena (seiches) are most common in shallow, open lakes, such as Lake Erie.

Water flows out of Lake Ontario into the St. Lawrence River at a rate of about 6 850 m³/s. By the time the river passes the mouth of the Saguenay River, about two-thirds of the way to the Gulf of St. Lawrence, water from numerous tributaries (e.g., the Ottawa, Richelieu, St. Maurice, Manicouagan, Chaudière, and Saguenay rivers) has increased the flow to 10 000 m³/s. At this point, the St. Lawrence is the second largest river in North America, after the Mississippi. Between Lake Ontario and the Gulf of St. Lawrence, the river drops in abrupt steps, creating a series of fluvial lakes (Lake St. Francis, Lake St. Louis, the La Prairie basin, and Lake St. Pierre) separated by narrow sections of faster flow.

Figure 6.1g

Air temperature, degree-days, and precipitation in selected centres of the Great Lakes–St. Lawrence basin

Selected centres	Ecozone	Air temperature (°C): Mean January maximum	Mean January minimum	Mean July maximum	Mean July minimum	Degree-days[a]: Heating (<18°C)	Growing (>5°C)	Precipitation: Mean annual rainfall (mm)	Mean annual snowfall (cm)	Days with measurable precipitation
Bagotville (Chicoutimi–Jonquière), Que.	Boreal Shield	−10	−22	24	12	5 839	1 475	641	345	115
Hamilton, Ont.	Mixedwood Plains	−3	−10	26	15	4 054	2 177	743	152	146
London, Ont.	Mixedwood Plains	−3	−11	26	14	4 144	2 121	779	212	168
Montreal, Que.	Mixedwood Plains	−6	−15	26	15	4 575	2 079	736	214	162
Oshawa, Ont.	Mixedwood Plains	−2	−10	25	15	3 984	2 080	755	126	117
Ottawa–Hull, Ont.–Que.	Mixedwood Plains	−6	−16	26	15	4 688	2 045	702	222	159
Quebec City, Que.	Mixedwood Plains	−8	−17	25	13	5 208	1 688	881	337	178
Sault Ste. Marie, Ont.	Boreal Shield	−6	−15	24	11	5 097	1 586	633	316	173
Sherbrooke, Que.	Atlantic Maritime	−6	−18	25	11	5 176	1 621	835	288	124
St. Catharines–Niagara Falls, Ont.	Mixedwood Plains	−1	−8	27	17	3 688	2 451	789	164	162
Sudbury, Ont.	Mixedwood Plains	−9	−19	25	13	5 407	1 680	636	267	98
Thunder Bay, Ont.	Boreal Shield	−9	−21	24	11	5 749	1 427	547	196	138
Toronto, Ont.	Mixedwood Plains	−3	−11	27	14	4 174	2 090	665	124	141
Trois-Rivières, Que.	Mixedwood Plains	−8	−18	26	14	4 950	1 879	805	242	154
Waterloo, Ont.	Mixedwood Plains	−3	−11	26	14	4 335	1 992	768	162	102
Windsor, Ont.	Mixedwood Plains	−1	−9	28	17	3 615	2 544	788	123	143

Note: Data based on 1961–1990 climatic normals.

[a] A unit of measurement of the deviation of the mean daily air temperature from a predetermined standard (at a particular location). For further details, see definition of degree-days in Glossary.

Source: Environment Canada (1994).

Figure 6.1h

Selected hydrographic information for the Great Lakes and the St. Lawrence River

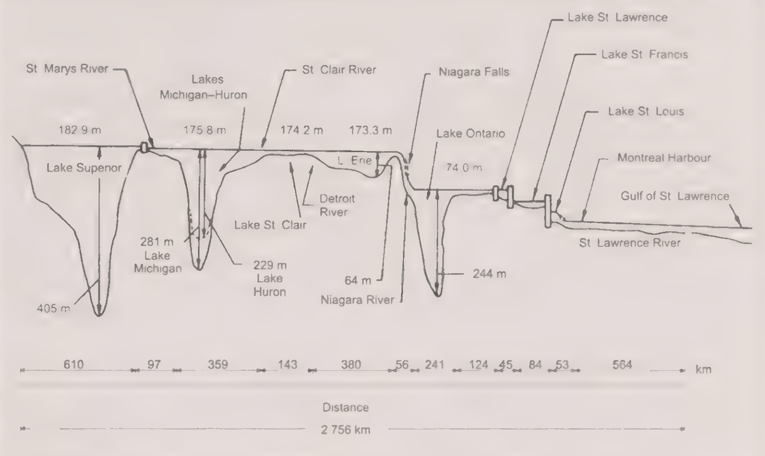
Water body	Level above sea (m): Mean	Range	Target	Length (km)	Width (km)	Shoreline length (km)	Depth (m): Average	Maximum	Volume (km^3)	Retention time (years)	Outflows (m^3/s): Mean	Maximum	Minimum	Outlet
Lake Superior	183.4	182.7–183.9	182.7–183.8	563	257	4 385	147	406	12 100	191	2 140	3 600	1 160	St. Marys River
Lake Michigan	176.5	175.6–177.5		494	190	2 633	85	282	4 920	99				Straits of Mackinac
Lake Huron	176.5	175.6–177.5		332	245	6 157	59	229	3 540	22	5 180	6 740	3 000	St. Clair River
Lake Erie	174.1	173.2–175.0		388	92	1 402	19	64	484	2.6	5 880	7 820	3 340	Niagara River
Lake Ontario	74.8	73.8–75.8	74.2–75.4	311	85	1 146	86	244	1 640	6	6 910	10 100	4 360	St. Lawrence River
St. Lawrence River				1 600		4 200								
at Cornwall											7 000	10 100	4 400	
at Pointe Claire	21.1	20.2–22.5					5.1	17.3			8 200	12 800	5 900	
at Montreal	6.3	5.1–8.7												
at Lake St. Pierre (inlet)											9 700			
at Quebec City											12 600			
at Baie-Comeau											16 800			

Notes:
1. The outflow from Lake Michigan and Lake Huron is considered jointly at the St. Clair River.
2. Only for Lake Superior and Lake Ontario are levels and outflows regulated (see Fig. 6.1a). Target levels and ranges for these lakes are specified in regulation plans approved by the International Joint Commission.
3. Numbers for levels and flows refer to monthly values.
4. Where ranges of flow or depth are presented for the St. Lawrence River, the information comes from the Levels Reference Study Board (1993) (Pointe Claire, Montreal) or Environment Canada, Ontario Region (Cornwall); for other locations, the source of information is St. Lawrence Centre (1996a).

Source: Whillans et al. (1992); Levels Reference Study Board (1993); Environment Canada and U.S. Environmental Protection Agency (1995b); St. Lawrence Centre (1996a); Environment Canada, Ontario Region, unpublished data.

In the estuary, which begins at the outlet of Lake St. Pierre and ends 555 km later in the Gulf at Pointe-des-Monts, three distinct zones can be observed: the freshwater estuary to Île d'Orléans; the brackish middle estuary to the Saguenay River, a biologically productive transition zone (ecotone) where fresh water and seawater mix; and the saline estuary, a marine environment. All three zones are subjected to tides, which cause the water levels at Île d'Orléans to fluctuate by 5 m and which twice daily reverse the direction of flow as far inland as Portneuf. At the boundary between the middle and maritime estuaries, the Saguenay River fjord forms three basins of very cold water, which have maintained enclaves of Arctic ecosystems.

Figure 6.1i
Depth and elevation profile of the Great Lakes and the St. Lawrence River



Source: Modified from Levels Reference Study Board (1993); Environment Canada, Ontario Region, unpublished data

Weather and climate

The weather in the Great Lakes–St. Lawrence basin is affected by three principal factors: air masses from other regions, the location of the basin within a large continental land mass, and the moderating effects of the basin's water bodies themselves. The prevailing movement of air is from the west, but the characteristically changeable weather of the basin is a result of alternating flows of warm, humid air from the Gulf of Mexico and, in the eastern portion of the basin, the Atlantic and cold, dry air from the Arctic. Temperature swings are much less than on the Prairies, where relatively dry air masses move in from the west or north. Mean temperatures in the basin in January and July range from –15°C and 18°C in Thunder Bay to –5°C and 23°C in Windsor (Fig. 6.1g).

Precipitation ranges from 700 mm in Thunder Bay to 1 200 mm in Quebec City (Fig. 6.1g; see also Fig. 5.1f in Chapter 5). More locally, temperature and precipitation are influenced by the Great Lakes, the St. Lawrence estuary, and the Gulf of St. Lawrence. In summer, increased summer sunshine warms the surface layer of the water bodies; in the fall and winter months, release of the heat stored in them moderates the climate near the shores. In winter, prevailing winds from the lakes and the Gulf of St. Lawrence create local snowbelt zones; among these are the Collingwood–Barrie–Orillia area southeast of Georgian Bay and the Niagara Peninsula–Buffalo region. At Quebec City, some of the most important snowstorms observed are associated with a northeast circulation behind depressions situated over the Atlantic coast or the Maritimes; this circulation brings moist air to the St. Lawrence, which stimulates snowstorms. The highest snowfalls tend to be associated with higher elevations, as is the case in the Laurentians to the north of Quebec City and in the Appalachians in Gaspé. Overall, the climate creates favourable conditions for agriculture in the southern parts of the basin.

Wildlife

The Boreal Shield ecozone north of Lake Superior, with its hilly topography, extensive outcrops of bedrock, cold climate, and relatively infertile soils, is much less biologically productive than the lands in the more southerly regions. The steep shorelines surrounding the many lakes are not suitable for wetlands and do not form natural harbours. Extensive stands of conifers dominate. Woodland Caribou, White-tailed Deer, Moose, Wolf, and Black Bear are characteristic mammals, although their numbers have decreased from earlier times. The waters of lakes Superior and Huron are similarly less biologically productive than the lower Great Lakes and the St. Lawrence. (For a more detailed description of the Boreal Shield ecozone, see Chapter 5.)

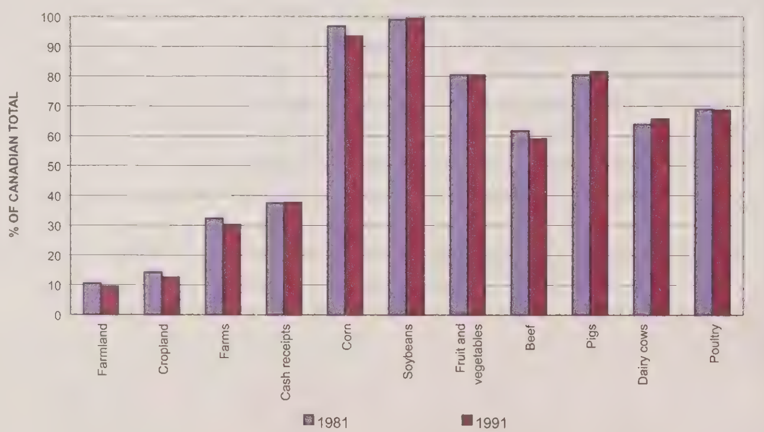
There is an ecological transition from the Boreal Shield ecozone to the southern Mixedwood Plains ecozone. Until European settlement, the latter was largely covered by forests, with patches of grassland in dry areas and numerous wetlands. Mixed coniferous and deciduous forests dominated. In the south, in a band from Windsor to the western end of Lake Ontario, was a northern continuation of the ecologically diverse and productive Carolinian forest. Much of the original forest cover of the ecozone has been removed, most notably the Carolinian forest in the Lake Erie Lowland ecoregion, where now only 8% of the land is forested. Small fragments and isolated stands remain in places such as the Rouge Valley in eastern Metropolitan Toronto and Bachus Woods near London. Less forestland means less habitat for all the native species of the ecozone.

The gently sloping shorelines around the lower Great Lakes favour the development of wetlands and natural harbours in flooded river mouths and shallow bays. These natural features are important to a variety of vertebrates that use them seasonally for breeding, feeding, and rearing their young. These same natural harbours were also the focus of early European settlement. As the towns and cities grew, many of the wetlands and other shoreline features were filled in and converted to other uses. European settlement also led to a steep increase in the rate of invasion of new species. Many of the now-common roadside plants are imports from Europe. Insect life in the Mixedwood Plains ecozone now includes large populations of parasites (such as cutworms) associated with nonnative crops and wildflowers, whereas native species that were important links in the food web, such as mayflies, are less numerous.

Beaver, Porcupine, Red Fox, and White-tailed Deer remain abundant in the Mixedwood Plains ecozone, but Wolf, Cougar, and other large predators that were once common are no longer found. Black Bears appear only occasionally, and only in the northernmost areas. Opportunistic birds such as Common Crow, House Sparrow, and Rock Dove and mammals such as Rat, Raccoon, House Mouse, Gray Squirrel, and Woodchuck have increased in abundance because they are tolerant of conditions in cities and the surrounding urban fringe areas. Waterfowl, shorebirds, and some native songbirds (e.g., those of forest habitats) continue to do well in the ecozone, which lies on a major migration flyway. Songbirds of grassland habitats have generally declined in numbers, however, probably owing to conditions within the ecozone as well as along their migration corridors and in their wintering habitat (see Chapter 10).

The aquatic ecosystem of the Great Lakes–St. Lawrence basin, although one connected system, contains distinct biological communities throughout its different parts. Lake Erie is the shallowest, warmest, and most productive of the Great Lakes; Lake Superior is the deepest, coldest, and least productive. Originally, Lake Trout and other salmonids, Walleye and other percids, and fish-eating birds and mammals were the predominant vertebrates atop the aquatic food web, and populations of Atlantic Salmon, Lake Trout, Lake Whitefish, and other food fishes were enormous. By the mid-1900s, however, many long-lived species had disappeared. The aquatic community has been greatly affected by physical alterations, overfishing, toxic chemicals, and the invasion or deliberate introduction of exotic species; in the lower Great Lakes, where it has been most altered, the fish community is now characterized by introduced Alewife and Rainbow Smelt as forage fish and trout and salmon species maintained by stocking programs.

Figure 6.2
Status of agriculture in the Mixedwood Plains ecozone, 1981 and 1991



Notes: "Corn" includes grain corn and silage corn; "fruit and vegetables" includes all vegetables, tree fruit, grapes, and tobacco; "beef" includes all cattle for meat production (beef cattle, slaughter cattle, and calves).

Source: Unpublished information from the State of the Environment Directorate, Environment Canada, based on the ecological classification project of Agriculture Canada and the State of the Environment Directorate and the Census of Agriculture (Statistics Canada) of 1981 and 1991.

The human element

Some 24.7 million Americans and 8.5 million Canadians live in the Great Lakes basin, most of them along the shores of the lakes. Another 7 million Canadians live along the St. Lawrence. The Great Lakes–St. Lawrence basin has been a centre for human settlement, agriculture, and manufacturing for well over 300 years. Today, 20 urban centres and well over 13 000 industrial plants (mostly in the United States) are found in the Great Lakes basin alone. The basin's agricultural operations produce 38% of all agricultural sales in Canada.

In Canada, most of this activity is centred in the Windsor–Quebec City corridor, or Mixedwood Plains ecozone. About 54% of all Canadians live here. The ecozone, which contains the country's two largest cities, has a population density of over 100 persons per square kilometre — 10 times higher than anywhere else in Canada. Agriculture accounts for 58% of all land use, a figure that rises to 66% in the Lake Erie Lowland ecoregion, which extends from Windsor to Toronto. The labour force, concentrated in the services and manufacturing sectors (Fig. 6.1e), accounts for 55% of Canada's gross domestic product.

The economy in the Boreal Shield ecozone presents a contrasting picture, dominated by resource activities such as mining, logging, and pulp and paper as well as smaller-scale hunting, fishing, and trapping. Industrial raw materials are sent south, where they are used in manufacturing or reprocessed into more valuable commodities and shipped elsewhere for manufacturing.

Overview of Human Activities and Environmental Issues

Agriculture in the Mixedwood Plains ecozone

In the Great Lakes–St. Lawrence basin, only the lands south of the Canadian Shield are well suited to agriculture — the area that corresponds to the Mixedwood Plains ecozone. Its climate is relatively humid and mild, with warm summers and cool winters. Growing degree-days range from 2 500 in Windsor to 1 700 in Quebec City (Fig. 6.1g). Fertile soils overlay carbonate-rich bedrock in a landscape of nearly level to rolling plains. Of all the ecozones in Canada, this is the one best suited to agriculture and the one most intensively cultivated — 58% of all land in the ecozone is farmland, of which 64% is cropland. With just 9% of the agricultural land in the country, the area accounts for 38% of all agricultural sales (Fig. 6.2). Almost all (97%) of the farm sales of Ontario and 68% of those of Quebec originate here.

Since the late 1700s, clearing, largely for agriculture, has reduced the once-predominant forest cover of the ecozone to less than 25% of the total land area, much of it in farm woodlots, hedgerows, and remnant stands. To create additional cropland, marshes were drained, largely since the late 1800s (Moss and Davis 1994). Deforestation was already causing soil erosion and fluctuations in local water supplies by that time. In the early 1900s, the predominant wheat economy gradually began to be replaced by small mixed farms, with combined harvests of crops, timber, and livestock. Soil erosion was better controlled and soil productivity maintained by using sod-based rotations and growing small grains and forages in rotation (Acton 1995).

In the 1940s and 1950s, larger, more specialized cash crop farms and livestock operations started to replace the small mixed farms. Corn, often grown in rotation with soybeans, became the main cash crop, especially in the southwest portion of the ecozone. As the century progressed, the area of farmland decreased as a result of pressure from residential and other nonagricultural land uses. Although it is a problem throughout the ecozone, urban expansion is a particular concern in the Lake Erie Lowland ecoregion and around Montreal. Throughout the lowlands, there was 14% less farmland in 1991 than in 1971; during the same period, the proportion of farmland used as cropland increased by 25%. Crops are generally grown on level land, and artificial land drainage is common, particularly in the Lake Erie Lowland ecoregion, the warmest and most intensively farmed part of the ecozone (see the "Lake Erie basin" section of this chapter), and the St. Lawrence Lowlands ecoregion. Agriculture is the predominant land use in the Lake Erie Lowland ecoregion, where cropland accounts for more than 80% of the farmland.

The more rolling landscape of the Manitoulin–Lake Simcoe ecoregion and parts of the St. Lawrence Lowlands ecoregion (the northern and eastern portions of the Mixedwood Plains ecozone) are less suitable for high-value crops, but they support a large dairy industry and beef, pork, and poultry production. These "fringe" areas, farther from the large urban centres, are seeing a steady and fairly rapid decline in active farms and farmland (A. Jarvis, Ontario Land Resource Unit, Agriculture and Agri-Food Canada, personal communication).

Some distinctive characteristics of agriculture in the Mixedwood Plains ecozone include the following:

- Areas where crops are grown are increasingly separated from areas where livestock is raised; moreover, significant portions of the crops grown in one region of the ecozone are used to feed livestock elsewhere in the ecozone.
- The primary role of local production is in supplying the large population nearby. Provincial farm sales (see Fig. 11.4 in Chapter 11) show that in Ontario, dairy, poultry, and eggs account for the most sales, and vegetables and pork follow closely behind. In Quebec, pork is second in sales, after dairy.
- Urban centres and agricultural areas are closer together here than anywhere else in Canada. Over 60% of farmland is within 50 km of an urban area, a figure that rises to 86% in the Lake Erie Lowland ecoregion. One of the results is the ongoing conversion of (often prime) farmland to other uses.

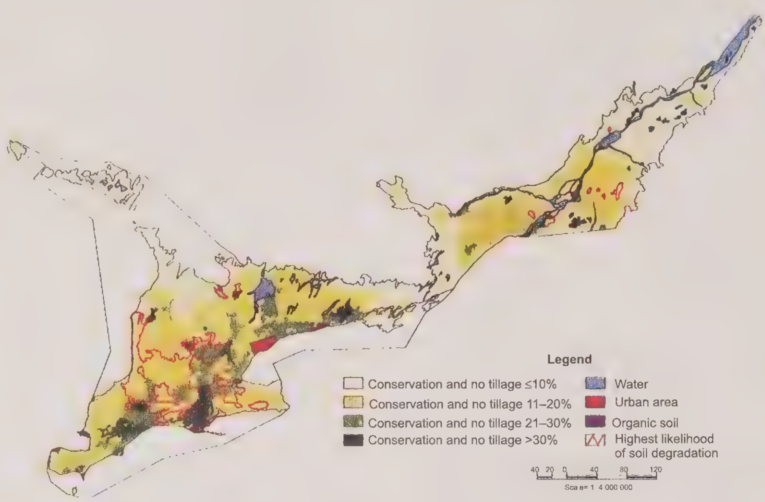
This distinctive form of agriculture has both benefits and environmental and social costs. The prime benefit is the efficiency (in terms of human resources and land, although with high use of energy) with which ample food is produced for the large population nearby. The costs are the stress on soil and water and on the sustainability of the farming system itself, the transformation of the landscape, a reduced diversity of species and habitats (see the "Biodiversity and habitat change" section of this chapter), and impacts on the structure of rural society.

Soil degradation

As discussed in more detail in Chapter 11, certain cultivation practices on vulnerable soil can lead to high rates of soil erosion, soil compaction, and changes in soil structure. These effects reduce fertility: erosion may reduce fertility by 50–100% in extreme cases (Wall et al. 1995), and compaction has been estimated to reduce yields by 10% across Canada (see Chapter 11). Erosion also leads to water pollution by soil particles and by agricultural chemicals (e.g., phosphates, pesticides) attached to them. Water erosion, compaction, and changes in soil structure are thought to be the main dangers for the cultivated soils of Ontario and Quebec (Acton 1995). A few soils also appear to have become acidified, probably by a combination of high fertilizer application and acidic precipitation.

The extent of erosion and compaction is estimated (often with the help of a computer model) from the properties of the soils and from information on cropping and tilling practices. Information on the former has become available in the National Soil Database of Agriculture and Agri-Food Canada; the latter is being collected in the Census of Agriculture of Statistics Canada. The estimates are fairly uncertain, but they provide ranges of risks and allow comparisons of different areas. Based on these methods, it has been estimated

Figure 6.3
Areas of the Mixedwood Plains ecozone most susceptible to soil degradation, 1991



Note: Conservation and no-tillage practices over 20% indicate areas where positive steps are being taken to sustain soil quality.

Source: Bretz (1995).

that, under conditions of bare soil, 52% of the cultivated area of Ontario and 47% of the cultivated area of Quebec are under "high to severe" risk of water erosion, compared with 20% in Canada overall (Wall et al. 1995). Compaction and structural degradation of soils are especially severe in Quebec, where more than 80% of soils under corn production are thought to be structurally degraded to some extent, and 20% are affected by compaction (Topp et al. 1995; see also Tabi et al. 1990 for a thorough review of the state of soils in Quebec). About 75% of clayey soils under corn/soybean culture in southwestern Ontario are also thought to be affected to varying degrees.

Corn is grown in wide rows, providing little soil cover. Corn depletes the soil of nutrients, which has to be compensated by heavy applications of fertilizer. In addition, corn-growing practices such as monoculture and conventional tillage lead to high rates of water erosion on silty soils and in rolling terrain. As cash crop farms became common in the 1950s, corn was grown on the same land year after year, sometimes in rotation with soybeans. This was especially the case in the Lake Erie Lowland ecoregion, where even today more than 35% of all Canada's corn is grown. Bare fields that are worked with heavy machinery when they are wet in early spring and late fall are also vulnerable to compaction and deterioration of soil structure. Clayey or silty soils under monoculture corn production are particularly susceptible (Topp et al. 1995).

Some of the more vulnerable and less productive land is now being converted to pastureland or taken out of agricultural production altogether, especially around the fringes of the ecozone. Some conservation practices also reduce or prevent soil degradation (see Chapter 11). Since 1991, Statistics Canada has kept statistics on the extent of these practices. In 1991, an average of only about 17% of the area tilled throughout the ecozone was tilled using conservation techniques. The most prevalent method, used on about 52% of the farms that reported conservation practices, was crop rotation. Other methods of conservation tillage included winter crop cover (15%), grassed waterways (11%), contour ploughing (5%), strip cropping (3%), and a variety of other practices.

These statistics, together with the soil properties data in the National Soil Database, are being used to identify areas that are most susceptible to deterioration in soil quality (Bretz 1995; MacDonald at al. 1995) and the likelihood of soil erosion (Wall et al. 1995). As shown in Figure 6.3, most of these areas are in south-central Ontario, with some small pockets in Quebec. The extent of such areas has been estimated to be 20% of all cropland in the ecozone (Bretz 1995). Using similar methods, Wall et al. (1995) estimated that changes in cropping and tilling practices between 1981 and 1991 reduced the risk of water erosion by 21% per hectare of tilled land in Ontario and by 6% in Quebec.

As yields under conventional and conservation tillage become comparable, farmers may see a short-term economic advantage (reduced energy and labour costs) in conservation or zero tillage, as well as the long-term advantage of soil conservation. A June 1994 survey of 600 farms in Ontario indicated a higher rate of conservation tillage than shown by the statistics for 1991. The same survey indicated that 64% of farmers with land adjacent to permanent waterways or wetlands maintain a buffer strip; in over 60% of cases, the buffer was at least 3 m wide (K.B. MacDonald, Agriculture and Agri-Food Canada, personal communication).

Agrochemicals and manure

As discussed in Chapter 11, synthetic fertilizers and pesticides increase and stabilize agricultural yields. However, inherent in the widespread use of chemicals is their potential to contaminate the environment and, for pesticides, to affect human health. This risk cannot be completely avoided, but it can be reduced by using less persistent, more specific pesticides and by practices such as integrated pest management.

Phosphorus from agricultural fertilizers is the main cause of nutrient loadings to, and eutrophication of, the lower Great Lakes, particularly Lake Erie, and the St.

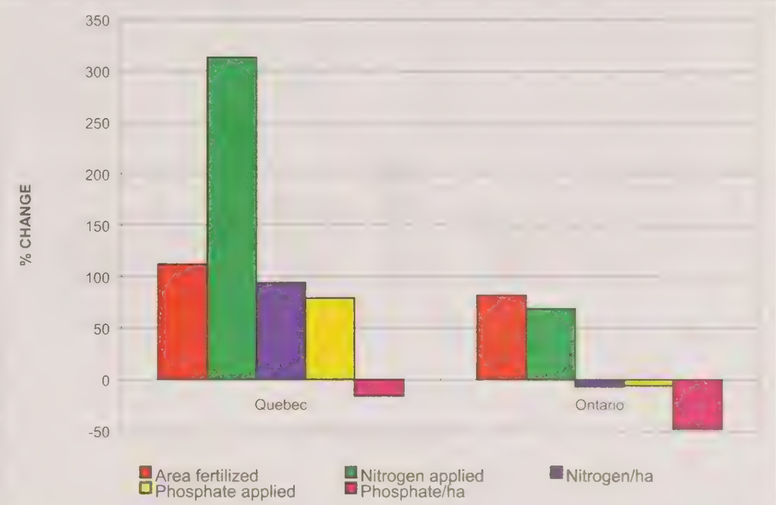
Lawrence River (for more detail on this issue, see the "Eutrophication of water bodies" section of this chapter). However, the problem is controllable. As phosphorus from fertilizers is quickly adsorbed by soil particles, phosphorus pollution from agriculture can be reduced by controlling soil erosion.

Although nitrogen fertilizers also contribute to eutrophication, the main threat of nitrogen fertilizers is nitrate pollution of drinking water. When present as nitrates, nitrogen dissolves in water, thus presenting a risk to groundwater as well as surface water. Of 1 300 Ontario farm wells tested in one large survey, 15% exceeded the maximum acceptable concentration of nitrate (Agriculture Canada 1993); a survey of 35 wells in potato-growing areas in Quebec found only 2 (6%) above the safe limit (Giroux 1995). Improperly managed manure and septic tanks are also sources of nitrogen pollution (Reynolds et al. 1995).

Areas with porous, sandy soils, such as the sandplains of southwestern Ontario and the sandy deposits along the St. Lawrence River (Giroux 1995), are most vulnerable to groundwater pollution. Sandy soils are also most at risk for contamination from bacteria in manure and septic tanks and from pesticides. Twenty-five percent of the 1 300 Ontario farm wells tested and 83% of the 35 wells tested in Quebec were found to be contaminated with bacteria above acceptable levels.

The farm well surveys indicate that, in groundwater, pesticides might be less of a health risk than nitrates and bacteria. In the Ontario survey, traces of pesticides (mostly atrazine) were found in 12% of the 1 300 wells, but only 2 wells contained higher levels than what is deemed safe by the Guidelines for Canadian Drinking Water Quality (Agriculture Canada 1993). The Quebec survey showed traces of aldicarb and atrazine in 31% of the 35 wells (Giroux 1995). Tile drainage significantly decreases leaching of contaminants to groundwater (Reynolds et al. 1995), although it may increase the risk of surface water pollution. The few cases of high pesticide concentrations in well water are usually due to careless handling and direct contamination through the well opening (Pupp 1989). The most serious health risk from pesticides appears to occur by direct exposure, either through the air or through contact while they are being applied.

Figure 6.4
Changes in fertilizer use in Quebec and Ontario between 1970 and 1990



Source: Statistics Canada (1994b).

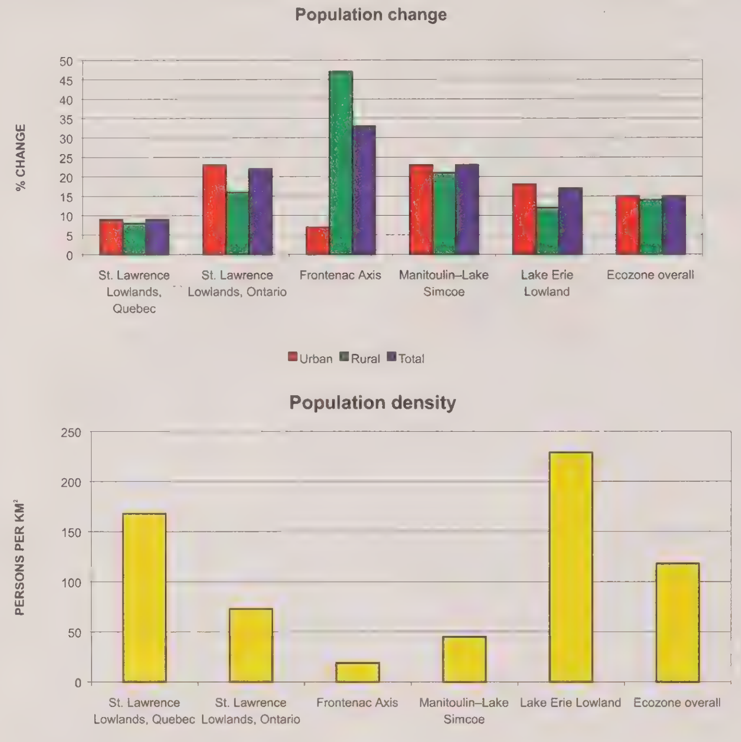
Long-lived herbicides, such as atrazine, also affect the quality of some of the major water bodies. Concentrations of atrazine measured in lakes Huron and Michigan are in the 20–35 ng/L range, whereas in lakes Erie and Ontario they rise to 70–110 ng/L (Schottler and Eisenreich 1994). The main source of atrazine to Lake Erie is its own basin, which contributes an estimated annual 30 t to the lake via its major tributaries. The largest source of atrazine to Lake Ontario, on the other hand, is Lake Erie, via the Niagara River. In Quebec, a close correlation was shown between drainage basins with intensive corn production and the concentration of atrazine and metolachlor in the waters that drain them (Berryman and Giroux 1994).

Current fertilizer and pesticide use in Ontario and Quebec presents a mixed picture. Nitrogen fertilizer is used in large amounts for corn production. As shown in Figure 6.4, there was a substantial increase in its use between 1970 and 1990. The increase, in absolute terms as well as in the amounts applied per hectare, was particularly pronounced in Quebec. This seems to reflect a rise in corn production. In Ontario, where there has been a shift from corn to soybeans, fertilizer use per hectare and total phosphate use actually declined. Corn production also calls for large amounts of agricultural pesticides — 64% and 55% of all herbicides applied in Quebec and Ontario, respectively (Ontario Ministry of Agriculture, Food and Rural Affairs 1994; Gorse 1995). Pesticide use increased considerably over the 20-year period between 1970 and 1990 (Statistics Canada 1994a).

Since the mid-1980s, however, less pesticide is being used, at least when measured by amounts of active ingredient if not by expenditure. In Ontario, for example, 28% less pesticide and 66% less atrazine (measured by tonnes of active ingredient) were used in 1993 than 10 years earlier (Ontario Ministry of Agriculture, Food and Rural Affairs 1994). This is partly due to the arrival of new pesticides on the market that are used in much smaller amounts; these new pesticides are also more specific,

Figure 6.5

Population change, 1981–1991, and population density, 1991, in the ecoregions of the Mixedwood Plains ecozone



Source: Census of Canada 1981 and 1991, as arranged for ecological classification by Statistics Canada, Agriculture and Agri-Food Canada, and the State of the Environment Directorate, Environment Canada.

less persistent, and less toxic to nontarget organisms. Both Ontario and Quebec have programs in place to reduce the use of pesticides. Quebec's plan aims at a reduction of 50% between 1992 and 2000 (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec 1991); Ontario's plan also calls for a 50% reduction between 1987 and 2002 (Ontario Ministry of Agriculture, Food and Rural Affairs 1994). The reductions are to be achieved using tools such as best management practices and integrated pest management. New techniques that use precisely targeted and timed applications are also being developed.

Switching to manure is one option to decrease the use of synthetic fertilizers, but manure is not without environmental problems. As the physical separation of crop and livestock production increases and as livestock operations become more intensive, the proper storage and disposal of manure become considerable challenges. Improperly stored or applied manure can contaminate groundwater as well as surface water. The amount of manure produced in Ontario and Quebec is equivalent to 177 000 and 88 000 t of nitrogen, respectively (Statistics Canada 1994b). This number is comparable to the total amount of commercial fertilizers used in the two provinces. However, commercial fertilizers are applied on nearly 80% of cropland, and manure is applied on only 20%. The two provincial governments now have programs in place to assist farmers in proper manure management and in resolving well water problems.

Changes in technology and energy use

Developments in agricultural technology are changing production practices and patterns, as well as the resulting impacts on the environment, and it is expected that they will do so at an accelerated pace in the future (Plucknett and Winkelmann 1995). Since the mid-1970s, two changes in particular have profoundly altered agriculture in the area. One was the development of new cultivars of corn that have shorter growing periods and can increase yields by 20% while requiring smaller amounts of nitrogen fertilizer. This has led to a dramatic shift in the areas of corn production. Between 1981 and 1991, Quebec's share of all grain corn grown in the ecozone increased from 15% to 27%, while at the same time farmers in southwestern Ontario switched a significant area of land from corn production to soybean production. The other change is the switch from the persistent herbicides of the 1970s (e.g., atrazine) to more specific and less persistent herbicides that can be applied in minute amounts (g/ha instead of kg/ha); this change has resulted in a 66% reduction in atrazine use. Genetically modified, pest-resistant corn is expected to become commercially available in the near future (Plucknett and Winkelmann 1995).

Other changes include the development of machinery for conservation tillage and targeted fertilizer applications, as well as procedures for integrated pest management. The latter techniques can result in time, fuel, and cost savings, in addition to reduced environmental impacts. Sophisticated new techniques for targeted pesticide and fertilizer application are being investigated as part of provincial programs to reduce pesticide use (Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec 1991). They include infrared and other tracking systems to detect the density of weeds or lack of fertilizer, targeted spot applications of chemicals, and "expert" computer systems to determine the optimum amounts, location, and timing for applications.

Such approaches, however, require sophisticated equipment, knowledge, and planning. They are therefore likely to accelerate the trend towards highly spe-

cialized, capital-intensive agribusiness. Education and technology transfer, which are part of the provincial programs, will make these new techniques available to a broader cross-section of farmers.

Social changes in the rural community
Throughout the country, there has been a movement away from remote areas towards, but not into, the metropolitan centres. At the same time, there has been a movement outward from the cores of these centres, such as Montreal and Toronto, into the surrounding smaller cities and rural areas (see Fig. 6.5). Growth rates between 1981 and 1991 were higher in the less densely populated areas, such as around Ottawa and north of Toronto, than in the urban centres (Research Sub-Committee of the Interdepartmental Committee on Rural and Remote Canada 1995).

Between 1981 and 1991, farm employment as a percentage of rural population in the Mixedwood Plains ecozone declined from roughly 18% to about 16% (1981 and 1991 Census of Canada), and even farmers now spend almost half their work time off the farm. Many of the new rural and small-town residents object to the "nuisance" effects of farming. Farm production can be noisy, smelly, and dusty and can have other effects that nonfarmers regard as a nuisance. The conflicts have become so frequent that Ontario now has "right to farm" legislation for agriculturally zoned land, and Quebec is considering such a move. Meanwhile, the new residents create economic and environmental stresses of their own: an increase in the number of septic tanks, for example, can exceed the ability of an area's soil and groundwater to remove or dilute pollutants, such as nitrates, bacteria, and even organic solvents. As lawns become larger, the use of pesticides expands; indeed, lawn pesticides now make up a significant portion of all pesticides being used (Gorse 1995).

Urbanization

Evolution of urban settlement
Historically, urban settlement in the Great Lakes–St. Lawrence basin was shaped largely by water. The earliest French settlement took place along the St. Lawrence and its tributaries: for example (using the modern names), at Quebec City in 1608, Trois-Rivières in 1634, Montreal in 1642, and St-Jean-sur-Richelieu in 1666. British settlement of Upper Canada began in the mid- to late 1700s, with the establishment of such towns as Niagara Falls, Hamilton, Toronto, Brockville, Trenton, and Cornwall, along the Niagara River, the north shore of Lake Ontario, and the upper reaches of the St. Lawrence. Both of Canada's largest cities were originally established on water routes, Montreal at the break in river transportation caused by the Lachine Rapids, Toronto at the "bridgehead" from the Lake Ontario–St. Lawrence system to the overland route to Georgian Bay and the upper lakes.

Not until the 1800s did substantial urban settlement begin to take place farther inland, as the forests were replaced by farms and industrial facilities. London, Kitchener, Guelph, Barrie, Peterborough, Shawinigan, and Jonquière were founded during this period. Invariably, however, their sites were on rivers (such as the Thames, the Grand, and the Saguenay) or on lakes (such as Lake Simcoe and Lac Saint-Jean), to supply both water for consumption and a means of transportation and power generation. The importance of waterways for transportation steadily declined with railway construction in the 1800s and the expansion of the road network.

In Quebec, urbanization continues to be closely tied to the St. Lawrence and its tributaries. About two-thirds of the population of Quebec is concentrated in a 10-km-wide strip along the St. Lawrence and Saguenay rivers; approximately 90% of these people reside in the Montreal, Quebec City, Trois-Rivières, Sherbrooke, and Chicoutimi–Jonquière metropolitan areas.

Urbanization in the 20th century
Since the 1920s, Canada has been a predominantly urban country, and today more than half the population lives in large cities (see Chapter 12). The Canadian economy has seen a marked shift from manufacturing to services, coupled with an increasing concentration of service employment in the metropolitan areas (Bourne and Olvet 1995).

The cities in the Great Lakes–St. Lawrence basin were founded along its first great highway, the St. Lawrence–Great Lakes water route. Along its shores or those of its tributaries, one finds today 15 of the 25 major Census Metropolitan Areas[1] of Canada, 13 of them in the Windsor–Quebec City corridor — the most heavily urbanized region of Canada, with two of Canada's three largest urban centres (see Fig. 6.1d).

The waterway remained the main route of transportation until the early 1900s, orienting the direction of movement (of people, the economy, and new organisms) and shaping the patterns of settlement. Since then, the railroads and then a network of highways and expressways (and increasingly air traffic) have taken over that role. Since the opening of the Seaway in 1959, deep-water ships can reach the port of Toronto, but few do so nowadays. Montreal, however, is still an important international port, the prime Canadian port for container ships.

Within city boundaries, Montreal is still Canada's most populous city (Japan External Trade Organization 1991); since the mid-1970s, however, the larger regional area (Census Metropolitan Area) of Toronto has surpassed that of Montreal in population.

The changing urban pattern
While the basin's metropolitan areas were growing, they were simultaneously spreading out into a form very different from that of the traditional compact, centralized city. This overall process of change has been summed up as "a broad scale 'implosion' of population and human activity into urban-centred regions and a regional

1. The general concept of a Census Metropolitan Area is one of a very large urban area, together with adjacent urban and rural areas that have a high degree of economic and social integration with that urban area. A Census Metropolitan Area is delineated around an urbanized core having a population of at least 100 000 (Statistics Canada 1994b).

scale 'explosion' of the urban centre into the surrounding countryside, small towns and villages" (Bryant and Lemire 1993). As the metropolitan areas took a growing proportion of the population and spread into formerly rural areas, the new suburbs accounted for the lion's share of their population increase. For example, more than 83% of the growth of the Greater Toronto Area's population between 1981 and 1991 took place outside the Municipality of Metropolitan Toronto, in the regional municipalities of Halton, Peel, York, and Durham (Bourne and Olvet 1995) (the Greater Toronto Area corresponds roughly with the Census Metropolitan Area but is somewhat more extensive). The city of Laval, north of the Island of Montreal, took the largest share of the growth of the Montreal metropolitan area between 1976 and 1991 (Bryant and Lemire 1993).

The effects of the regional-scale "explosion," however, extended beyond the suburbs, and they increasingly continue to do so. Across Canada, people are moving to intermediate urban and to metro-adjacent rural regions (Research Sub-Committee of the Interdepartmental Committee on Rural and Remote Canada 1995). Bourne and Olvet (1995) noted "significant [population] flows at the regional scale" to the "the local hinterland" of Toronto — cities such as Kitchener–Waterloo to the west (57% growth between 1971 and 1991), Oshawa to the east (nearly 100% in the same period), and Barrie to the north (32.5% growth between 1986 and 1991) (Bourne and Olvet 1995). Similarly, Bryant and Lemire (1993) found that many small municipalities in the vicinity of Montreal, such as St-Lazare, Blainville, L'Assomption, Lavaltrie, and Varennes, grew by over 40% between 1986 and 1991.

This evolving urban pattern is linked to the changing nature of manufacturing, the growing share of services in the economy, and the shifting retailing patterns. Manufacturing and service industries and retail centres relocate or are newly established in the suburbs and metro-adjacent satellite communities, and a new "multi-nucleated urban form" (Bourne and Olvet 1995) or "truly integrated megalopolitan structure" (Bryant and Lemire 1993) is emerging, particularly around Toronto or Montreal. At the same time, there are signs that a social decline may accompany the decline in population in the inner city of large metropolitan centres (Brunet 1995).

Environmental implications of urban growth and change: the case of southern Ontario

The environmental implications of urban development in the Toronto area go as far back as 1832, when outbreaks of cholera in the newly founded Town of York were attributed to the contamination of drinking water by sewage and garbage (Metropolitan Toronto Municipality 1995). In the years that followed, much of the hardwood forest was cleared, eliminating wildlife habitats and contributing to erosion, runoff, and the silting of watercourses. Industrial development and coal-fired electricity generation led to air pollution. Road and railway construction cut across natural wildlife corridors; river valleys provided convenient routes for roads, railway lines, and sewers, as well as a means of "disposing" of garbage. Ravines and wetlands were filled in for urban development or used as garbage dumps. The removal of stone and sand from the bed of Lake Ontario for construction, the dumping of waste materials, and filling and other works along the shore polluted the water, destroyed fish habitat, and otherwise altered the lake's natural processes. On land, industrial operations left a legacy of seriously contaminated soils. After the Second World War, rapid suburban growth, facilitated by widening car ownership, reduced the area of productive farmland and reinforced many environmental impacts as well as spreading them farther afield (see Chapter 12).

The administrative boundaries of the regional municipalities constituting today's Greater Toronto Area correspond fairly closely with the natural boundaries of the "Greater Toronto Bioregion" (Royal Commission on the Future of the Toronto Waterfront 1991): the Niagara Escarpment to the west, the Oak Ridges Moraine to the north and east, and Lake Ontario to the south (see Fig. 6.29).

Within these boundaries, there are still substantial tracts of prime agricultural land beyond the urban fringe. Farming in the "urban shadow," however, tends to be seen as no more than a holding operation pending eventual conversion of the land to subdivisions and shopping malls. A few residual wetlands survive, although most have been filled or drained. A considerable number of Environmentally Sensitive Areas and Areas of Natural or Scientific Interest have been identified by municipalities, the provincial Ministry of Natural Resources, and conservation authorities. All these features are to some extent under constant threat from urban development or urban-related uses. Waste management in the Greater Toronto Area, in particular the quest for new landfill sites, has for several years been a contentious public policy issue. Additional information on the Greater Toronto Area is presented later in this chapter in the section on the "Lake Ontario basin."

The water quality of lakes Simcoe and Scugog is impaired by recreational use and by waterfront development, including retirement communities. In a 1993 survey, Toronto-area planners expressed concerns about waterfront planning; waste management; conflicts between urban development and the agricultural base; the protection of river valleys, other natural features, and Environmentally Sensitive Areas; and "the impact of urban development on the environment" generally (Bryant and Lemire 1993).

The two natural features that define the landward limits of the Greater Toronto Bioregion are also subject to serious pressures. The Niagara Escarpment is southern Ontario's most prominent physical feature: extending from the Niagara River to beyond the Bruce Peninsula, its landforms and wildlife, including rare and endangered plants and animals, together with beautiful scenery and dramatic vistas, have attracted designation by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) as a World Biosphere Reserve. The Niagara Escarpment also provides a diversity of outdoor recreational opportunities conveniently near to the largest concentration of Canadians. Its features are also, however, highly tempting to developers; the stream valleys that penetrate the Niagara Escarpment are

equally attractive to highway and sewerage planners; and, above all, the Niagara Escarpment is a rich source of construction aggregates. As a result, the Niagara Escarpment is an almost classic case of land use conflict.

To the north, the Oak Ridges Moraine, although less conspicuous than the Niagara Escarpment, is hardly less a case of land use conflict. To the eye a broad tract of rolling, still heavily wooded upland, it, too, provides important wildlife habitat and considerable biodiversity. It also contains the headwaters of a number of rivers and streams that flow both southward through the Greater Toronto Area to Lake Ontario and northward to Lake Simcoe and Georgian Bay, rivers that supply water to many communities as well as providing important fish habitat and recreational opportunities. Easily accessible from Toronto, crossed by the main routes to the northern "cottage country," and offering favourable construction conditions, the Oak Ridges Moraine has attracted many "country estate" developments and a variety of other essentially urban-related activities, and what were once narrow country roads have become heavily used highways. As a result, woodlands have been removed, habitat destroyed, erosion encouraged, natural corridors disrupted, water quality degraded, and water tables drawn down.

The environmental impacts of urbanization in the Windsor–Quebec City corridor are most intense in the metropolitan regions of Toronto (the Greater Toronto Area) and Montreal (the Montreal Urban Community), but they can be found in and around every city and town. One case that is perhaps particularly noteworthy is the Niagara "fruit belt," the relatively tiny area on the Niagara Peninsula that is endowed with a unique combination of soils and climate that enable it to produce rich crops of peaches, grapes, and other tender fruits and that today is gaining a growing reputation for the quality of its wines. Its orchards and vineyards are, however, under continuing threat from the expansion of St. Catharines and smaller towns, to which substantial areas of fruitland have already been lost. A similar situation prevails for the Laval market gardens.

Physical restructuring

Dredging, water diversions, canalization, and regulation of water levels for navigation, power generation, and shoreline property protection have all modified the ecosystems of the Great Lakes–St. Lawrence basin. In some cases, these modifications have had mainly local impacts. One great engineering feat, however — the St. Lawrence Seaway and Power Project — has had major widespread ecological, economic, and social impacts.

The St. Lawrence Seaway–Great Lakes Waterway

In the early 1800s, several obstacles prevented ships from reaching the Great Lakes from the ocean. Several series of rapids prevented ships from reaching Lake Ontario from the St. Lawrence River, and Niagara Falls formed a barrier to Lake Erie. Further, the rapids at Sault Ste. Marie blocked access to Lake Superior. Canals and locks were built to allow small vessels to bypass these obstacles. In 1824, the Lachine Canal was opened, bypassing the rapids in front of Montreal, and in 1845, the first Beauharnois Canal allowed ship passage past the Soulanges Rapids west of Montreal. The Welland, Rideau, Trent–Severn, and other canals opened direct water routes to the interior.

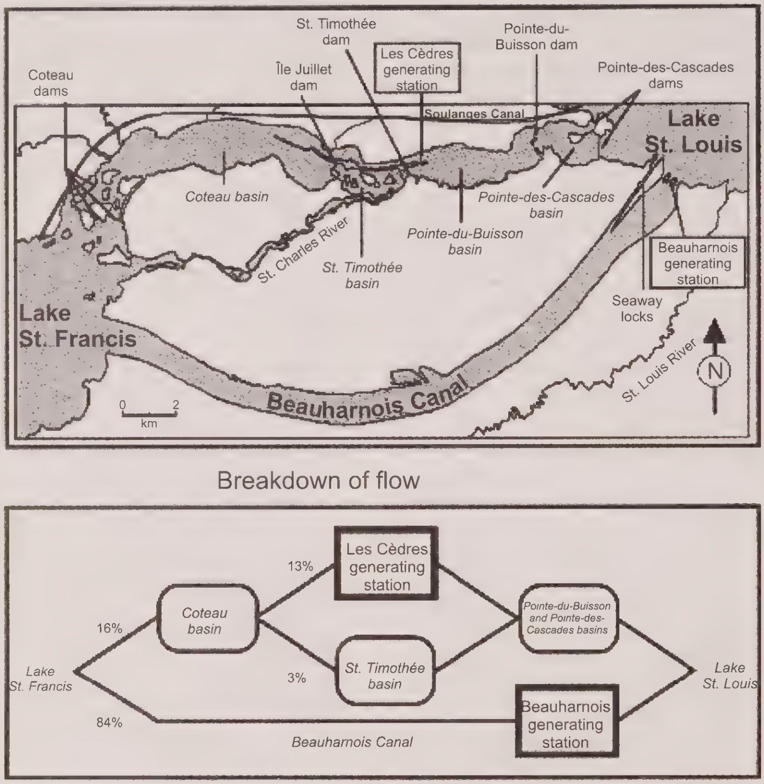
The current Seaway system, built jointly by Canada and the United States between 1954 and 1959, consists of the open waters of the Great Lakes and St. Lawrence together with all the linking canals, locks, dams, control structures, and harbours. In the St. Lawrence section alone, seven locks were built and 87 million cubic metres of material excavated (Lasserre 1980). During the same period, the shipping channel between the estuary and the first lock at Montreal was deepened and widened. More than half of this 370-km stretch of the St. Lawrence had to be dredged. The project changed both the landscape and the social fabric of the flooded area along portions of the St. Lawrence River. For example, an estimated 6 500 Canadians were relocated to accommodate the navigation and power pool upstream of the Moses–Saunders dam at Cornwall, for which flooding extended 60 km upstream (Ontario Great Lakes/Seaway Task Force 1981).

Large vessels (up to 222 m long) can now reach the Great Lakes. Grain, iron ore, coal, and limestone comprise 85% of the freight, most of which travels between ports within the system. The total economic impact of the Seaway system on the Canadian economy is estimated to be \$2–4 billion annually (Sub-Committee on the St. Lawrence Seaway 1994). More than 200 million tonnes of cargo move on and through the Seaway each year. Over the past two decades, however, the volume of traffic and cargo has declined (see the "St. Lawrence Lowlands ecoregion" section of this chapter).

Significant drops in elevation in various sections make the St. Lawrence River ideal for electric power production. The first hydroelectric generating facilities, built by private firms in the late 1800s, were modest run-of-river projects that used only a small fraction of the flow. They caused no perceivable change in upstream or downstream water levels and did not hinder fish migration. The first Beauharnois hydroelectric generating station, built between 1929 and 1932, was of this type and initially diverted only 15% of the river flow towards the Beauharnois Canal. However, to meet the growing demand for electricity, the station was gradually expanded and the intake canal enlarged to the point where 84% of the river flow now passes through the power station (A. Michaud, Planification des équipements, Hydro-Québec, personal communication; see also Fig. 6.6). As more water was diverted, additional structures were built to maintain water levels in the Beauharnois Canal or to create recreational reservoirs.

Hydro generating stations were also built near Cornwall–Massena, Niagara Falls, and the St. Marys River at Sault Ste. Marie. The Moses–Saunders hydroelectric generating station, a Canada–U.S. project, was built between 1954 and 1958. It resulted in the disappearance of the rapids at the head of Lake St. Francis and the creation of a reservoir upstream, Lake St. Lawrence. This dam is the main control structure regulating the outflow of

Figure 6.6
Structures and river flow in the St. Lawrence between Lake St. Francis and Lake St. Louis: the Beauharnois Canal and generating stations



Note: Diversions through the Beauharnois Canal may reach 95% on some occasions (A. Michaud, Planification des équipements, Hydro-Québec, personal communication).

Source: Robitaille (1994).

Lake Ontario and is operated according to the Lake Ontario regulation plan. At Niagara Falls, water is diverted from the Niagara River above the falls and returned to the river below the falls. The diversion and flow over the falls are regulated by the International Niagara Board of Control of the International Joint Commission (IJC) (Levels Reference Study Board 1993). Two hydro power facilities are located in the Michigan portion of the St. Marys River, and one is located in Ontario. These facilities plus the compensating works are operated according to the Lake Superior regulation plan (Levels Reference Study Board 1993).

Water diversions
Major water diversions occur at four locations (Fig. 6.1a):

- the Long Lac and Ogoki diversions redirect approximately 153 m^3/s of water from the Albany River into the Lake Superior basin for hydro power generation;
- the Chicago Sanitary and Ship Canal diverts 91 m^3/s of water into the Mississippi River system for navigation and wastewater removal;
- the New York State Barge Canal diverts about 30 m^3/s of water from the Niagara River during the navigation season; and
- about 270 m^3/s are diverted from Lake Erie into the Welland Canal.

None of these diversions has a significant effect on lake levels (Levels Reference Study Board 1993).

Environmental effects
The restructuring of the water body that has occurred because of the construction of the Seaway and major water diversions has had significant environmental impacts. For instance, the widening and deepening of the shipping channel and the construction of auxiliary structures such as embankments, jetties, and dikes have increased the water flow in the centre of the channel and decreased the flow along the shore. For long distances, the waters from the Great Lakes flow in the central channel, and the waters from the St. Lawrence tributaries flow along the shores without mixing. Nearshore sedimentation and summer heating have increased in lakes St. Francis, St. Louis, and St. Pierre, resulting in the spread of flats of aquatic grasses.

The channel and the structures of the Seaway have also seriously interfered with the migration routes of many aquatic species. In the upper estuary, the channel coincides with the route of most migrating fish. As ship traffic increased, dramatic declines occurred in the commercial catches of these species (Robitaille et al. 1988). The locks and dams farther up the Seaway provided an additional obstacle to migration to spawning areas.

Dredging is undertaken in ports, harbours, canals, and connecting channels in the Great Lakes, primarily to improve navigation. Several million tonnes of sediments annually have been dredged from ports and channels, about two-thirds of which were dumped in confined facilities because they were too polluted for open water disposal (Sediment Work Group 1990).

The regulation of water levels has had local repercussions on aquatic and riparian, or river valley, habitat. The outflows from lakes Superior and Ontario are regulated according to plans approved by the International Joint Commission (IJC). Although regulation structures keep lake

levels within specified ranges (Fig. 6.1h), they cannot strictly control them. High lake levels in 1985–1986 caused flooding, erosion of shorelines, and damage to lakeshore properties, prompting calls for action among property owners, particularly around Lake Erie (Levels Reference Study Board 1993). After an extended study, however, the IJC concluded that although regulating was technically feasible for all five lakes, the costs were greater than the economic and physical benefits. It recommended other measures to mitigate the effects of fluctuating water levels on shoreline property owners (Levels Reference Study Board 1993).

Fisheries

Fish species and their habitats

One hundred and fifty-nine species of native fish were reported to have existed in the Great Lakes basin, 11 of which have now been extirpated (Table 6.1). Four of those were found only in the Great Lakes (Miller et al. 1989). Species are thought to separate into genetically distinct stocks, adapted to specific habitats and remaining distinct by segregating during spawning. For example, the Great Lakes were the home of a wide variety of Lake Trout stocks, adapted to exploit different types of spawning substrates, depths, and times (Krueger and Ihssen 1995). Historically, Lake Superior had the largest variety of shallow nearshore and deeper offshore spawning sites, with as many as 259 distinct sites thought to have existed (Thibodeau and Kelso 1990). The high genetic or stock diversity that has been inferred from the diversity of spawning habitats and morphological variation of adults was probably responsible for allowing Lake Trout to exploit these different habitats (Burnham-Curtis et al. 1995). In contrast, most contemporary Lake Trout stocks in the Great Lakes spawn only at the nearshore and relatively shallow spawning sites.

Great Lakes habitats can be divided into the broad categories of *nearshore* and *offshore*, with each supporting characteristic species of fish (Busch and Sly 1992). Fish populations are often classified in relation to these habitats as well as according to where they feed (i.e., *bottom* or *benthic* species, and *open-water* or *pelagic* species) and what they eat (i.e., their position in the food web) (U.S. Department of the Interior 1995). Nearshore habitats are warmer and more productive than offshore habitats and are also more affected by human activities. About 80% of Lake Erie's surface area is considered nearshore habitat (U.S. Department of the Interior 1995); as a result, despite having only 11% of the total surface area of the Great Lakes, Lake Erie has a fishery that is as productive as that of all the other Great Lakes together (see Table 6.3 below).

Except Lake Erie, all of the Great Lakes are considered oligotrophic (low-productivity) lakes. In their pristine state, they were dominated by Lake Trout — a cold-water offshore fish — as the top piscivore[2]; Lake Ontario also had Atlantic Salmon. The main food source of these fish consisted of benthic macroinvertivores (sculpins, some ciscoes) and open-water planktivores such as Lake Herring. A parallel branch of the food web consisted of a large open-water macroinvertivore, Lake Whitefish. The top piscivore in the mesotrophic (medium-productivity) waters of Lake Erie and in the more productive embayments of the other lakes was Walleye.

About 200 species of fish are found in the St. Lawrence River, its tributaries, its estuary, and the Gulf of St. Lawrence (Gagnon 1995). In the St. Lawrence River, fish communities were adapted to the series of fluvial lakes, separated by sections of faster flow and rapids. Some species, such as the American Eel, spent part of their life in salt water and migrated up the St. Lawrence and even the Great Lakes to complete their life cycle. Since the 1950s, the physical restructuring of the river, habitat modifications, and even local eutrophication have had serious adverse effects on species that were migratory, long-lived, or intolerant to changes in habitat. Fish communities have become dominated by undemanding sedentary species with high turnover rates (Robitaille and Mailhot 1989). Some local fish populations, requiring a specific habitat or diet, have greatly diminished in abundance or have disappeared alto-

Table 6.1
Number of living and extirpated native fish species in the Great Lakes basin

Location	No. of native species	
	Living	Extirpated
Lake Nipigon basin	38	0
Lake Superior	43	0
Lake Superior tributaries	68	2
Lake Michigan	74	6
Lake Michigan tributaries	116	2
Lake Huron	71	6
Lake Huron tributaries	97	2
Lake St. Clair[a]	96	1
Lake Erie	84	6
Lake Erie tributaries	103	5
Lake Ontario	81	10
Lake Ontario tributaries	110	2
Great Lakes basin	148	11

[a] Includes the St. Clair and Detroit rivers.

Source: Bailey and Smith (1981); J. Fitzsimons, Department of Fisheries and Oceans, personal communication.

2. Piscivores are species whose diet consists of more than 75% fish, macroinvertivores are those whose diet consists of at least 75% macroinvertebrates (insects, crustaceans, annelid worms, etc.), and planktivores are those with a diet of at least 75% plankton (U.S. Department of the Interior 1995).

Table 6.2
Changes in St. Lawrence fish populations due to habitat alterations

Population and status	Suggested reasons for change in abundance
Muskellunge population of Lake St. Louis, density is lower today than in the 1930s	Disappearance of areas of the lake with moderate currents; development of grass beds, to the advantage of Northern Pike, a competitor of Muskellunge (Pageau and Lévesque 1964; Lebeau 1983; Dumont 1991).
Striped Bass population of the St. Lawrence estuary, seems to have disappeared in the mid-1960s	Physical modifications to the environment caused by the construction of the Seaway: direct (reproduction) or indirect (predator species) effects. Overfishing or poaching in wintering areas (Beaulieu et al. 1995).
Atlantic Salmon population of the Jacques Cartier River, disappeared in the 1930s, reintroduced in the 1980s	Loss of access to spawning grounds during construction of the dam near the mouth of the river (Vladykov 1949).
American Shad population of the St. Lawrence River and the Ottawa River	Loss of access to spawning grounds in Lake of Two Mountains and the Ottawa River (Provost et al. 1984).
Rainbow Smelt population of the south shore of the St. Lawrence estuary	Degradation of the primary spawning site, in the Boyer River, caused by crop and livestock production (Robitaille and Vigneault 1990; Trencia et al. 1990).
Lake Sturgeon population of Lake St. Francis, threatened	Loss of access to spawning grounds during the construction of dams at Beauharnois and later Cornwall (Cuerrier 1946; Dumont et al. 1987).
Lake Sturgeon population of Lake of Two Mountains, population rebuilding	Large-scale mortality caused by winter anoxia in 1950 (Mongeau et al. 1982).
Copper Redhorse populations of the Richelieu, Yamaska, and Mille Iles rivers	Degradation of preferred habitat, primarily as a result of agricultural practices. Competition with carp (Mongeau et al. 1986, 1992).

gether from fluvial lakes, tributaries, and embayments of the estuary (Table 6.2; see also Box 6.1).

The only long-term data from which to evaluate trends in fish populations are the records of commercial fish catches. These have been kept for the Great Lakes since 1867 and for the St. Lawrence since the early 1920s. However, these trend records must be interpreted with caution. In addition to changes in fish populations, they also reflect changes in gear used (e.g., the type of net), shifts in preferences, the effect of restrictions on allowable catch, and other variables. Also, they do not reflect the catches from the increasingly important recreational fishery. Some of the more significant of the recent trends are described below.

Human activities and their effects on fish populations

Human activities have dramatically altered fish stocks in the Great Lakes–St. Lawrence basin. Lake Ontario, the St. Lawrence River, and their tributaries used to support the greatest Atlantic Salmon population in the world; by 1900, however, the species had disappeared from Lake Ontario as a result of overfishing and obstruction and deterioration of spawning habitat (Government of Canada 1991b). Lake Sturgeon underwent catastrophic declines by the early 1900s in lakes Ontario and Erie and a few decades later in the other lakes. By the 1950s, overfishing, habitat degradation, and the impact of the Sea Lamprey had caused the disappearance of Lake Trout from all of the lakes but Lake Superior and isolated areas in Georgian Bay and had brought severe declines in Walleye, Lake Whitefish, Lake Herring, and other species. The disappearance of controlling predators (Lake Trout and Burbot) led to an explosion in populations of the nonnative Alewife and Rainbow Smelt, which was compounded by the increased productivity from the high input of anthropogenic nutrients in the 1960s and early 1970s (see the "Eutrophication of water bodies" section of this chapter). As a consequence, concerted efforts were initiated to manage human activities in the basin and to restore its fish populations.

Today, the Great Lakes–St. Lawrence basin depends heavily on yearly stocking of millions of hatchery-reared salmonids, chemical control of the Sea Lamprey, control of nutrient inputs, and fishing quotas. These ongoing manipulations, along with the effects of new species that periodically establish themselves (see the section on "Biodiversity and habitat change"), make this system quite unstable and prone to imperfectly understood fluctuations in the populations of fish and other aquatic organisms.

The abundance of some native Great Lakes fish species has increased dramatically since the early 1980s. Lake Whitefish catches now reach or exceed historic levels in lakes Superior, Michigan, and Huron, and the species is also increasing in lakes Erie and Ontario, but to a lesser extent. Lake Herring in Lake Superior have increased more than 10-fold. The reason for these changes is not clear but may relate to co-occurring declines in Rainbow Smelt, a predator of Lake Whitefish larvae. Walleye abundance has rebounded in lakes Huron and Ontario, and the population has returned to historic levels in Lake Erie (Hatch et al. 1987).

On the other hand, since the mid-1980s, there has been a considerable, unexplained decline in the abundance of Yellow Perch in Saginaw Bay on Lake Huron and in lakes Ontario, Erie, and Michigan. The suspected causes are declining productivity resulting from reduced nutrient inputs, overfishing, and Zebra Mussels (U.S. Department of the Interior 1995).

Commercial and recreational fisheries

For the St. Lawrence, the main commercial fishery is the saltwater catch in the estuary and the gulf; in 1990, the saltwater catch was 74 300 t, compared with 1 000 t for the freshwater fishery (St. Lawrence Centre 1992b). Historically, the freshwater fishery focused on two peak fishing periods: the migration of American Shad, Walleye, and Lake Sturgeon in the spring, and the migration of American Eel, Lake Whitefish, and Walleye in the fall.

Recreational and commercial freshwater fisheries in the St. Lawrence River harvest 22 species in all (Robitaille et al. 1992). Figure 6.7 indicates trends from 1920 to 1984 for the four most important species — Lake Sturgeon, Walleye, Channel Catfish, and American Eel.

At present, the most important commercial fishery occurs in the Lake St. Pierre region (Robitaille et al. 1992). In 1970, the commercial fishing of Walleye and Northern Pike was prohibited upstream from Trois-Rivières owing to high concentrations of mercury. Commercial fishing operations in Lake St. Pierre were redirected to species that contained lower mercury levels, such as Yellow Perch.

The once-prominent commercial fishery in the Montreal area declined after the 1940s, partially because of a deterioration of aquatic and riparian habitats. However, another important factor was competition from the expanding recreational fishery. Mailhot (1990) reported that 212 000 recreational fishermen spent 2.4 million days fishing along the St. Lawrence River in 1985, harvesting over 3 000 t of fish. More than 80% of the fishing took place between Cornwall and Sorel, particularly on Lake St. Louis, whereas another 15% occurred on Lake St. Pierre. Walleye, Yellow Perch, Northern Pike, and two non-indigenous trout (Rainbow and Brown) were the prime species sought.

In the Great Lakes, commercial fish catches amounted to about 31 500 t in 1994, 57%

Box 6.1
The case of the Copper Redhorse

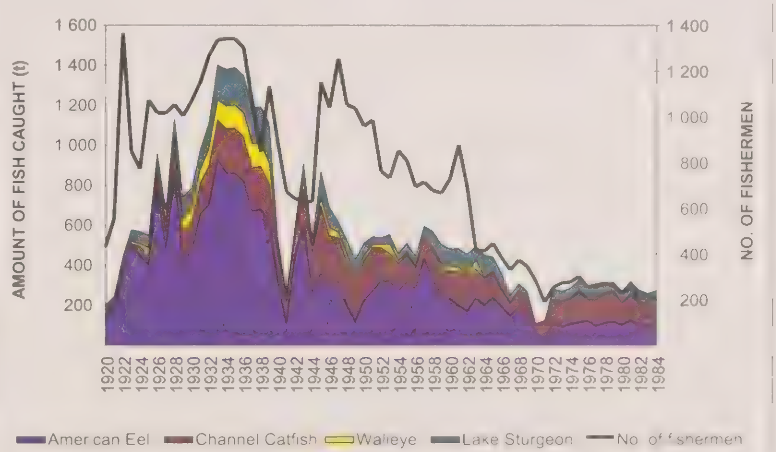
Redhorses belong to a family of bottom-feeding, freshwater fishes that also includes suckers. In all the world, the Copper Redhorse occurs only in a few waterways of southwestern Quebec — most notably in the Richelieu and des Mille Îles rivers and those portions of the St. Lawrence–Ottawa system immediately to the east and west of Montreal (Burnett et al. 1989). It feeds almost exclusively on molluscs, using highly specialized pharyngeal teeth, and its preferred habitats are sections of the river with moderate flow, steep banks, and a hard, flat bed (Comité d'intervention 1995). Already rare at the time of its discovery in the 1940s, the Copper Redhorse seems to have disappeared from most of its historic range over the past 30 years (Boulet et al. 1995). Currently, it is found, on rare occasions, only in a short stretch of the Richelieu River, and the only known remaining spawning site is downstream from the Chambly Rapids of the river.

The main factor that has placed the Copper Redhorse at risk of eventual extinction is the spreading of grass flats caused by eutrophication (mostly of agricultural origin) and other habitat modification (Mongeau et al. 1992). Quite recently, evidence was found of blocked maturation of gonads in females of the species and an inability to expel their eggs (Branchaud and Gendron 1993). Organochlorine pesticides are suspected of playing a role in this phenomenon (for brief discussions of the potential hormone-mimicking role of organochlorine contaminants, see the "Persistent toxic chemicals" section of this chapter and Chapter 13).

Since 1987, the Copper Redhorse has been designated as threatened by COSEWIC, and it will soon be designated a threatened species under the Quebec Act Respecting Threatened or Vulnerable Species. *A series of interim actions has been proposed to prevent the disappearance of the species (Comité d'intervention 1995).*

Figure 6.7

Commercial catches and number of fishermen in freshwater sections of the St. Lawrence, 1920–1984



Source: Dominion Bureau of Statistics, fisheries statistics, 1920–1944; Robitaille et al. (1992)

of which was in Canada (Table 6.3). The landed value of Canadian and U.S. commercial fisheries in the Great Lakes in 1994 was $67.6 million ($39.8 million of it in Canada), and total economic benefits were estimated to be about four times as high. The main commercial species today are Yellow Perch and Lake Whitefish, along with Walleye and Rainbow Smelt in Lake Erie. Since the 1960s, sport fishing has risen in importance, with estimated catches as high as those in the commercial fishery (W.-D. Busch, U.S. Fish and Wildlife Service, U.S. Department of the Interior, personal communication). The large recreational fishery relies in part on stocked salmonids.

Alewife and Rainbow Smelt

Alewife, a marine species, was reported in Lake Ontario as early as 1873 but underwent a dramatic increase in the 1950s in lakes Ontario and Michigan and to a lesser extent in Lake Erie. Together with Rainbow Smelt, it became the main pelagic planktivore in the Great Lakes when Lake Trout and Lake Herring (as predator and prime planktivore, respectively) disappeared and increased nutrient loading sharply increased the food supply. The large-scale stocking of salmonids since the 1970s was begun partially to control this population explosion. Alewife and Rainbow Smelt are now the primary prey species in the lower four lakes. Rainbow Smelt also support a valuable commercial fishery in Lake Erie.

The ecological role of the two species is complex. They provide the food source for the stocked salmonids and other fish species high in the food webs. However, they also prey on the larvae of Lake Trout, Lake Herring, and Lake Whitefish — restoration of these three species therefore may remain difficult as long as Alewife and Rainbow Smelt are abundant. Alewife have also been implicated in causing a thiamine deficiency in Lake Trout and Atlantic Salmon, which interferes with their reproduction (see below).

There has been a considerable reduction of these two prey species since the mid-1980s, associated with reduced phosphorus loadings to the lakes and heavy stocking of their predators. Fisheries managers are now trying to maintain a delicate balance between prey, stocked predators, and nutrient supply. Thus, the number of hatchery-reared salmonids annually released into the lakes has been reduced considerably (see below).

Restoration of Lake Trout and other salmonids

Lake Trout was the dominant piscivore and a major commercial species in the four oligotrophic lakes until the 1950s. By the mid-1960s, however, it had disappeared, except for isolated areas of lakes Superior and Huron. In the 1960s, a large-scale stocking program of Pacific salmon (mainly Chinook and Coho) and several species of trout (Lake, Rainbow, and Brown) was introduced in all the lakes to control the exploding populations of Alewife and Rainbow Smelt, restore Lake Trout populations, and provide for a recreational fishery. By 1989, more than 40 million salmonids were being stocked annually; by 1995, this figure had been reduced by almost 30% in response to the above-mentioned declining numbers of Alewife and Rainbow Smelt.

The success of the stocking programs has depended on control of the Sea Lamprey. By 1972, chemical controls being used throughout the Great Lakes had reduced lamprey populations by 80–90%. Lamprey spawning in the St. Marys River, however, could not be fully controlled by this method, and there are now as many lamprey in Lake Huron as in all the other lakes together. Wounding rates in salmon and Lake Trout are 20–50 times higher than in the other lakes, putting stocking success and Lake Trout restoration in jeopardy in the northern portion of Lake Huron (Schleen 1992).

The establishment of self-sustaining Lake Trout populations in the Great Lakes is an objective under the Strategic Plan for the Management of the Great Lakes Fisheries (Great Lakes Fishery Commission 1980) and was incorporated into the 1987 revision of the Great Lakes Water Quality Agreement (IJC 1988) as an ecosystem objective for Lake Superior. Lake Trout are also considered to be an ecosystem

Table 6.3

Landed weight and value of commercial fish catches in the Great Lakes, 1994

Water body	United States			Canada			Total for both countries		
	Landed weight (t)	Value ($)	Unit value ($/kg)	Landed weight (t)	Value ($)	Unit value ($/kg)	Landed weight (t)	Value ($)	Unit value ($/kg)
Lake Superior	1 118	2 300 917	2.06	707	720 989	1.02	1 826	3 021 906	1.66
Lake Michigan	7 800	17 003 292	2.18	0	–	–	7 800	17 003 292	2.18
Lake Huron	2 036	4 344 175	2.13	3 921	7 788 574	1.99	5 957	12 132 749	2.04
Lake Erie and Lake St. Clair	2 458	4 108 455	1.67	12 872	29 965 576	2.33	15 330	34 074 031	2.22
Lake Ontario	42	112 588	2.70	566	1 277 261	2.26	607	1 389 849	2.29
Total	13 453	27 869 426	2.07	18 066	39 752 400	2.20	31 519	67 621 826	2.15

Note: Dollar values for U.S. catches (originally in US $) were converted to CDN $ by taking 1.00 US $ as 1.30 CDN $.

Source: *Canadian data*: J. Tilt, Fish and Wildlife Branch, Ontario Ministry of Natural Resources, personal communication; *U.S. data*: Great Lakes Science Center, National Biological Service, U.S. Fish and Wildlife Service, Ann Arbor, Michigan.

indicator for the deep offshore waters of the other oligotrophic lakes (Ryder and Edwards 1985). In Lake Superior, remnant wild stocks have recovered slowly but steadily. Successful restoration is now thought to depend on "prudent management of naturally reproducing stock through reduction of fishing effort and Sea Lamprey abundance" (Hansen et al. 1994). In the other lakes, Lake Trout reproductive success has been disappointingly low (Marsden and Krueger 1991; Marsden 1994). Although spawning and fry emergence have increased, very few of the fry appear to survive to the yearling stage. Several factors have been implicated, including Alewife predation on Lake Trout larvae (Krueger et al. 1995), reduced availability of prey to juveniles, organochlorine contaminants (Cook et al. 1993), and a thiamine deficiency caused by a parental diet consisting almost exclusively of Alewife or Rainbow Smelt (Fisher et al. 1996).

The levels of organochlorine contaminants in salmonids have declined considerably since the 1970s (see the "Persistent toxic chemicals" section), but this change has not resulted in increased reproductive success. Recent contaminant levels do not appear to be sufficiently high to be the major or sole cause of early fry mortality (Fitzsimons 1995; Fitzsimons et al. 1995). The thiamine deficiency, however, appears to be an important factor. Thus, Alewife as the dominant offshore prey species may interfere with the successful restoration of Lake Trout while at the same time being necessary for the Pacific salmon.

Some of the introduced, river-spawning species have also been reproducing. For instance, Chinook Salmon and Coho Salmon have established self-sustaining populations in all of the Great Lakes (U.S. Department of the Interior 1995). A few Ontario streams, such as the Credit River and Wilmot Creek, used to be stocked with Atlantic Salmon in attempts to restore this once-indigenous fish to Lake Ontario, but returns were very low.

American Eels and their fishery

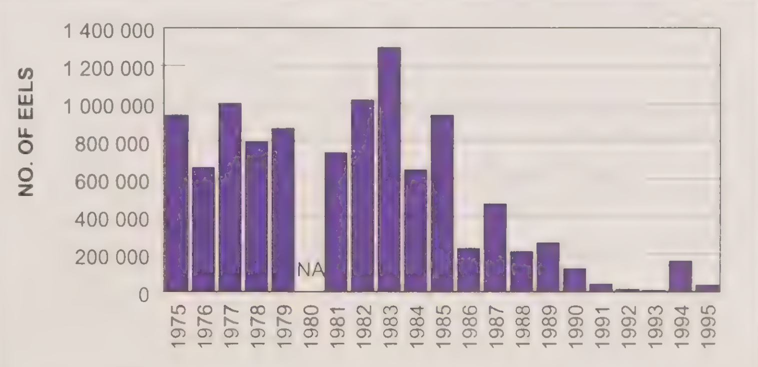
The American Eel harvest has been a traditional activity in the Quebec portion of the Great Lakes–St. Lawrence system, particularly in the estuary. The first European colonists were quick to imitate the Aboriginal peoples, who caught eels and smoked them for winter food reserves (Bourget 1984). Abundant and easy to catch, eels were a staple of the early settlers' diet until their first harvests were ready. Originally, most eels were caught in the upper estuary, near Quebec City, where they acclimatized before returning to the ocean. In the 1960s, however, this zone of acclimatization apparently shifted towards the middle (saltwater) estuary; since 1965, the eel fishery has become mostly a saltwater fishery (Robitaille and Tremblay 1994).

American Eel is a unique indigenous species in the St. Lawrence and Lake Ontario. Eels spawn in the Sargasso Sea, southwest of Bermuda, at around 20 years of age. At 2–8 years of age, they enter the St. Lawrence River and Lake Ontario to spend the next 12–18 years feeding in the tributaries. However, eel migrations were blocked in 1958 by construction of the Moses–Saunders dam on the St. Lawrence River. During the 1970s, the commercial fishery expanded, and the number of eels in the lake was not enough to support the fishery. Therefore, in 1974, Canadian officials had an eel ladder constructed at Cornwall to allow upstream migration. However, records at the eel ladder show a radical drop in the number of migrating eels since 1983 (Fig. 6.8). As it is mature fish returning to the sea that constitute the bulk of the St. Lawrence catch, it can be expected that this same decline will show up in commercial harvests there after a time lag.

Several hypotheses have been advanced to explain the decline of the eel stocks, but none has yet been widely accepted. Suggested causes are reduced access for ascending eels, a lower reproductive potential due to contamination, changes in the strength and position of the Gulf Stream (affecting larvae dispersion), and overfishing (see, for example, Castonguay et al. 1994). Habitat modifications in the St. Lawrence River may also be implicated; however, habitat changes occurred in the 1950s, and eel declines were not observed until the 1980s. Another issue of concern is the lack of knowledge about conditions in the Sargasso Sea, which may be affecting the eels at the egg and larval stages.

The most likely explanation is a combination of widespread overfishing between

Figure 6.8
Number of eels at the Cornwall eel ladder, 1975–1995



NA = no data available

Source: Ontario Hydro; Ontario Ministry of Natural Resources

1975 and 1980 and a reduction in the number of adults reaching their spawning grounds (Robitaille and Tremblay 1994). Higher prices for eels and the decline in stocks of more valuable species led to increased interest in the eel fishery in Lake Ontario in the 1970s. The combined effect of increased catches and a decline in the size of eels in the catch led to a 660% increase in the harvest of small eels between 1965 and 1978, jeopardizing the strength of eel cohorts descending the river in the following years. At roughly the same time, fishermen along the east coast of the United States started to harvest eels for the international market, rather than just for bait. The late 1970s saw an unprecedented increase in fishing effort and catches throughout the species' range (Axelsen 1996). As there is only one population of the species in North America, the generalized decline in catches means that the fortunes of eel fishermen everywhere are closely linked to the moderation they all exercise in harvesting this shared resource.

Biodiversity and habitat change

Relatively young (on an evolutionary time scale) yet diverse communities of plants, animals, fungi, and microbes have evolved in the Great Lakes–St. Lawrence basin since the retreat of the glaciers 10 000 years ago. Diversity contributes to the integrity of an ecosystem, giving it the resilience to withstand a multitude of stresses without deterioration. The presence of sufficient undisturbed habitat is the basis that allows these diverse biological communities to survive (see Chapter 14).

As settlement in the basin accelerated over the last 300 years, its habitat was more and more claimed by humans. People restructured the land for agriculture and cities and used the water for navigation, generation of electricity, and shoreline development. Exotic species were brought into the basin. Added to these disturbances were waste products — nutrients and toxic substances — released into the remaining habitat.

Exotic species

From time to time during the continuing evolution of ecosystems, new species successfully invade a system. After the initial disturbance, the ecosystem eventually develops a new balance that includes the introduced species. People are often responsible for the introduction of these exotic species, from disease-carrying organisms to plants and fish. The St. Lawrence River provides a natural route for new species to enter into and spread throughout the Great Lakes–St. Lawrence basin. But the movement of people and goods that began with European settlement caused an increase in introductions that greatly surpassed anything experienced until then (Fig. 6.9), and the invasion continues to this day.

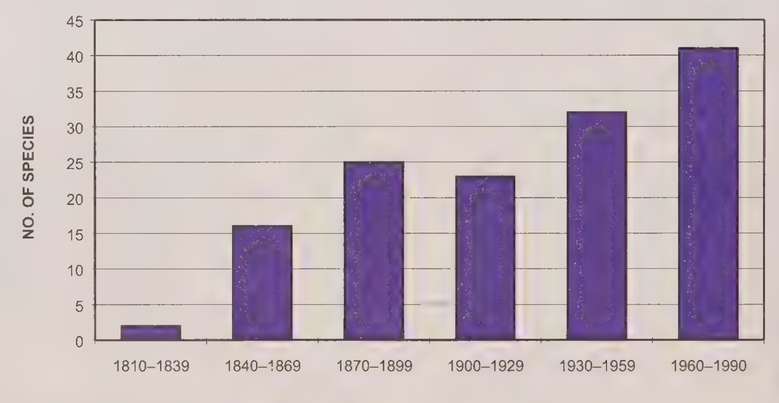
The specific details of introductions vary: they may occur through deliberate or unintentional releases from gardens, aquariums, hatcheries, or fish farms, from ballast or bilge water of ships, or by migration through canals. Some invaders are transported along roads and highways. The rate of introductions has increased steeply since the early 1960s, coinciding with the opening of the St. Lawrence Seaway and a dramatic increase in overseas shipping traffic: 29% of all known exotic species in the Great Lakes basin have arrived since 1959 (Mills et al. 1993). However, probably fewer than 10% of all the known new species entered through or along canals (Mills et al. 1993).

The most numerous exotic species are plants (59 species), followed by fish (25), algae (24), and molluscs (14). Among the plants are the Watercress (introduced in 1847), Purple Loosestrife (1869), and Black Alder (early 1900s); among the fish are the Chinook Salmon (1873), Common Carp (1879), and Ruffe (1986); and among the molluscs are the Zebra Mussel and Quagga Mussel (1980s).

Introduced species are present at almost every level of the Great Lakes food web, but for the most part little is known about the resulting changes in the invaded ecosystems. Although species diversity in an ecosystem is always dynamic, human activities can accelerate these dynamics, with uncertain consequences. Some invaders, however, are known to have ecological or economic impacts on the Great Lakes (Table 6.4).

Some introductions, such as Coho Salmon, Chinook Salmon, and Brown Trout, have had both positive and negative impacts. These species, which have to be stocked, feed on the Alewife, another exotic, and thus compensate for an imbalance in the food web that occurred with the near disappearance of Lake Trout as a top predator fish. They also support a large and economically valuable sport fishery. On the other hand, through competition, preda-

Figure 6.9
Number of nonindigenous aquatic species introduced into the Great Lakes, 1810–1990



Source: Mills et al. (1993).

tion, and habitat alteration, they may adversely affect native predatory species (Krueger and May 1991). Common Carp, White Perch, and other introduced species have become accepted as sport and commercial fish in some lakes.

Of those introduced species that now reproduce naturally in the Great Lakes, three have had particularly dramatic impacts (H. Regier, Institute for Environmental Studies, University of Toronto, personal communication):

- The Sea Lamprey had contributed to the collapse of Lake Trout, Lake Herring, Lake Whitefish, and cisco populations by the 1940s and has caused millions of dollars in damage to sport and commercial fisheries. It will continue to cost millions of dollars to reduce the lamprey's abundance to levels that will allow the restoration of native species.
- The Common Carp has contributed to the destruction of many wetland habitats and spawning areas.
- The Zebra Mussel has had a substantial effect on the populations of other molluscs (eight species have been extirpated in Lake Erie) and on fish habitat. The increased clarity of the water has favoured the growth of rooted plants over plankton, and the mussel has shifted the food chain towards bottom-feeding (benthic) and away from open water-feeding (pelagic) species. Whether food supplies for fish have been permanently depleted is not yet clear.

Table 6.4

Species introduced into the Great Lakes basin with demonstrable ecological or economic impacts

Species	Date	Impacts	
		Ecological	Economic
Sea Lamprey	1830s	–	–
Purple Loosestrife	1869	–	
Alewife	1873	+/–	+/–
Chinook Salmon	1873	+/–	+/–
Common Carp	1879	–	+/–
Brown Trout	1883	+/–	+
Aeromonas salmonicida[a]	1902		–
Coho Salmon	1933	+/–	+/–
White Perch	1950s	–	+
Eurasian Watermilfoil	1952	–	–
Glugea hertwigi[b]	1960	–	–
Ruffe	1986	–	
Zebra Mussel	1986	–	–

Note: + indicates positive impact
– indicates negative impact
+/– indicates that the species had both positive and negative impacts. For example, ecologically, Brown Trout prefer cold water and feed on Alewife in the lakes, but they also outcompete native Brook Trout when the two species cohabit in streams. Economically, Common Carp is an important commercial species in some locales but has adverse impacts on wetland habitats.

[a] Bacterium that causes furunculosis and other infections afflicting Pacific salmon and trout in hatcheries. This disease has not been reported in wild fish.

[b] A fish parasite that caused high mortalities of Rainbow Smelt (an important prey afflicting fish and valuable commercial species) in lakes Erie and Ontario during the 1960s and 1970s.

Source: Mills et al. (1993).

Wildlife at risk

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) annually assesses Canada's native mammals, birds, fish, reptiles, amphibians, and plants and assigns levels of susceptibility. Table 10.19 in Chapter 10 shows all species, subspecies, and populations of all types of wildlife listed by COSEWIC as endangered or threatened, identifying the provinces, territories, and ecozones within which each is found. Table 10.20 in the same chapter summarizes the number of endangered and threatened species, subspecies, and populations in each province or territory and in each of the country's ecozones. As of April 1995, for the Mixedwood Plains ecozone, 27 species were considered endangered and 32 threatened.

As well as COSEWIC, a number of other groups, using similar classification techniques but different terminology, have also identified wildlife at risk. Provincial and state natural heritage programs have identified 100 species of plants, mammals, birds, fish, reptiles, and invertebrates in the Great Lakes basin as critically imperilled, imperilled, or rare. Of the critically imperilled species, 77% occur exclusively or predominantly, or have their best-known populations, in the basin (Nature Conservancy 1994). Thirty-one natural ecological community types were also identified as rare or imperilled. Coastal marshes, shorelines, lake-plains (former beds of glacial lakes), and tributaries accounted for 71% of the unique biodiversity of the Great Lakes basin.

For the St. Lawrence basin, 155 species (110 plants, 19 birds, 14 fish, 6 reptiles, 5 mammals, and 1 amphibian) have been identified as priority species under St. Lawrence Vision 2000, the new St. Lawrence Action Plan (Comité Technique "Espèces" 1995; see also Box 6.2). Table 6.5 lists the animal species considered priorities under St. Lawrence Vision 2000.

Wetlands

Wetlands play an essential role in the life cycle of many species of birds, mammals, fish, amphibians, and reptiles (Table 6.6). They serve as spawning grounds and nurseries for fish and as nesting grounds, staging areas, and migration stopovers for birds. Many populations that are normally widely dispersed concentrate in wetland areas during critical stages of their life cycle (Dodge and Kavetsky 1995). Wetlands are also highly productive, providing food for both inland and open-water species.

Habitat loss and degradation of wetlands in the Great Lakes basin have been of concern to resource managers and the public alike. On the Canadian side of the basin, Lake Erie has the most coastal wetlands (about 17 500 ha), followed by Lake Ontario (about 12 000 ha). The other lakes have less than 5 000 ha each (Smith et al. 1991). It has been estimated that, by 1982, 1.45 million hectares, or 61% of the original coastal and inland wetlands in southern Ontario, had been converted to other uses (Snell 1987). Most of the remaining 0.93 million hectares of wetlands were in the "near north" area of southern Ontario, on the Canadian Shield. Wetland losses have been heaviest in regions of intensive urbanization and agriculture. Some areas in southwestern Ontario have lost 80–100% of their original wetlands (Snell 1987; Whillans et al. 1992).

Box 6.2
St. Lawrence Action Plan/St. Lawrence Vision 2000

The first St. Lawrence Action Plan (1988–1993), a cooperative effort of the governments of Canada and Quebec, had the following specific objectives, which were to be reached by 1993:

- *to reduce by 90% the liquid toxic waste discharged by 50 targeted industrial plants;*
- *to develop plans for remediating contaminated federal sites and restoring wetlands;*
- *to conserve 5 000 ha of wildlife habitat and create a marine park (now termed marine conservation area) at the mouth of the Saguenay River;*
- *to develop and implement recovery plans for a number of threatened species; and*
- *to produce a report on the state of the environment of the St. Lawrence.*

The following were achieved by the 1993 target date:

- *effluent from the 50 plants had been reduced by almost 75%;*
- *an impact assessment for the decontamination of the Lachine Canal and scenarios for sections of the ports of Montreal and Quebec had been prepared;*
- *5 000 ha of natural area had been protected, and the boundaries of the Saguenay National Marine Conservation Area had been set;*
- *recovery plans for threatened species had been developed;*
- *several state of the environment reports had been produced, and a synthesis report on the first five years was almost completed.*

In addition, biogeographic regions in the St. Lawrence were defined, the St. Lawrence Centre was established, and new industrial and cleanup technologies were developed and implemented (Governments of Canada and Quebec 1993).

St. Lawrence Vision 2000 (1993–1998), the second phase, focuses on the river and, according to priority, seven of its tributaries. Its long-term objectives are to:

- *reduce liquid toxic effluents and virtually eliminate discharges of persistent toxic chemicals;*
- *prevent or reduce agricultural pollution;*
- *restore degraded sites;*
- *preserve biodiversity;*
- *encourage citizens to help in protection and restoration;*
- *protect the health of people along the river; and*
- *improve knowledge of the system and disseminate information to decision-makers.*

Some specific objectives have been identified under each of the long-term objectives.

In 1994, the community interaction program was launched as part of St. Lawrence Vision 2000. Under this program, citizens in environmental groups get involved in restoring habitats, cleaning up riverbanks, and conserving fragile ecosystems. To date, 79 such projects have obtained $2.11 million in government support, and it is estimated that about the same amount has been contributed by citizens' groups.

The reasons for wetland losses along the St. Lawrence are similar (Robitaille et al. 1992). In addition, because of a shorter growing season in this region, farmers advance the timing of spring planting through earlier drainage of flooded fields after snowmelt. This reduces habitat for fish and waterfowl at a critical time in their life cycle.

Protected and undisturbed areas
Table 6.7 lists important sites for the conservation and protection of habitat in the Great Lakes–St. Lawrence basin. The IUCN (World Conservation Union, formerly the International Union for the Conservation of Nature and Natural Resources) categories of protected area are described in Box 14.4 in Chapter 14. Biosphere reserves, established under UNESCO's Man and the Biosphere (MAB) Programme, respond to a range of objectives, including scientific research, training, monitoring, and conservation. The Ramsar sites are considered "wetlands of international importance." Although each type of protected area operates with different management objectives, the conservation of biodiversity is becoming increasingly important to all (see Chapter 14).

Apart from habitats in protected areas, a few small fragments of original plant communities along the St. Lawrence have remained virtually unaffected by human activity. Most are located in isolated areas, including a number of islands in the river. Plant diversity is very high in these areas, reflecting the diversity of the lowlands in their pristine state.

Eutrophication of water bodies
All terrestrial and aquatic plants depend for growth on sunlight, water, and nutrients, such as phosphorus, nitrogen, and potassium. However, the presence of excessive amounts of nutrients in a body of water can produce more organic matter

than the water's natural purification processes can handle. This is known as nutrient enrichment or eutrophication, and it can be a natural process or it can be accelerated by human activity.

The earliest source of human-caused eutrophication was the sewage from human settlements. In the first half of the century, most such eutrophication occurred in lake embayments or at the mouths of streams and local waterways that were used to dispose of household wastes and sewage (Sly 1991). These are still where the highest concentrations of nutrients are found in the Great Lakes today (Fig. 6.10). After the Second World War, rapid population growth, the shift to a largely urban population, and the increased use of phosphorus in detergents led to large-scale eutrophication, which affected all the lakes, particularly Lake Erie. As fertilizer use and manure production increased, agricultural non-point sources of nutrients became important contributors, particularly in the Lake Erie basin and some of the intensively cultivated drainage basins along the St. Lawrence River. Lake Erie, via the Niagara River, is also the largest source of nutrients to Lake Ontario; the largest sources to the other lakes are their own tributaries (Neilson et al. 1995).

The increases in nutrients discharged to water bodies in the 1960s and 1970s greatly raised nutrient concentrations (see Fig. 6.11), productivity, and algal growth. This led to a number of secondary effects:

- The respiratory cycle of the algae led to large fluctuations in oxygen levels between day and night, and algae decomposition led to large decreases and even to outright absence of oxygen in some lake bottom waters in late summer (e.g., the central basin of Lake Erie). Certain insect larvae, bottom-dwelling invertebrates, and fish could not tolerate these levels. As a consequence, the mix of fish and other aquatic species shifted from those requiring oxygen-rich waters, such as Lake Trout and mayflies, to those that could tolerate the changed conditions, such as chironomids, Common Carp, Alewife, and Rainbow Smelt (Reynoldson and Hamilton 1993).

Table 6.5
List of animal species for priority consideration under St. Lawrence Vision 2000

Endangered species or populations	Species of economic interest
Reptiles	**Fish**
Spiny Softshell Turtle	American Eel
Spotted Turtle	Atlantic Herring
Fish	Atlantic Tomcod
Copper Redhorse	Rainbow Trout
Rainbow Darter	**Birds**
River Redhorse	Barrow's Goldeneye
Birds	Blue-winged Teal
Caspian Tern	Common Moorhen
Horned Grebe	Northern Pintail
Roseate Tern	

Source: Comité technique "Espèces" (1995).

Table 6.6
Great Lakes–St. Lawrence basin species dependent on wetlands for part or all of their life cycle

Species	Use of wetland
Bald Eagle, Osprey	Nesting area
Mallard, American Black Duck, Wood Duck, Blue-winged Teal, Canada Goose	Nesting, migration stopover, staging area
American Bittern, Red-winged Blackbird	Frequent summer residents
Largemouth Bass, Northern Pike	Adult habitat and spawning/nursery areas
White Sucker, Gizzard Shad, Common Carp	Opportunistic use as spawning, nursery, or feeding areas in different seasons of the year
Common Snapping Turtle, Mudpuppy, Bullfrog	Primary habitat
Muskrat, Mink, Red Fox	Food and habitat

Source: Herdendorf (1992).

- The large mats of *Cladophora* covering the beaches and nearshore shoals destroyed critical fish spawning grounds. Increased turbidity in nearshore areas also reduced the growth of rooted aquatic plants and adversely affected the habitat of fish such as Largemouth Bass and Northern Pike.
- The excessive amounts of algae interfered with commercial and sports fishing, with other human uses (swimming, boating, etc.), and with the quality of drinking water. The effects were particularly severe in shallow Lake Erie, resulting in reports of the lake dying.

In contrast to the Great Lakes, the small fluvial lakes of the St. Lawrence are flushed rather efficiently by the river. Exceptions occur where efficient flushing is prevented by large structures (e.g., the small La Prairie basin, where a dike was built for the St. Lawrence Seaway). Eutrophic environments in the St. Lawrence are primarily found in a number of tributaries that drain agricultural drainage basins (e.g., the Boyer, Yamaska, L'Assomption, Richelieu, and Chaudière rivers) and in their plumes of discharge in the St. Lawrence (Ministère de l'Environnement du Québec 1993). By the end of the summer, clumps of stringy algae and

Table 6.7

Important sites for the conservation and protection of habitat in the Great Lakes–St. Lawrence basin

Protected areas	Area (ha)
IUCN[a] categories	
I (Nature reserve or wilderness area)	16 802
II (National park)	59 921
III (Natural monument)	746
IV (Habitat/species management area)	26 906
V (Protected landscape or seascape)	99 758
VI (Managed resource protected area)	252 302
National parks	
Point Pelee, Ont.	1 564
St. Lawrence Islands, Ont.	410
Georgian Bay Islands, Ont.	2 560
Bruce Peninsula, Ont.	26 630
Biosphere reserves	
Long Point, Ont.	26 250
Niagara Escarpment, Ont.	207 000
Mont St. Hilaire, Que.	5 500
Charlevoix, Que.	448 000
Ramsar sites	
Baie de l'Île Verte National Wildlife Area, Que.	2 028
Cap Tourmente National Wildlife Area, Que.	2 398
Lac Saint-François National Wildlife Area, Que.	2 214
Long Point, Ont.	13 730
St. Clair National Wildlife Area, Ont.	244
Point Pelee National Park, Ont.	1 564

[a] IUCN areas apply to the Mixedwood Plains ecozone.

Source: National Conservation Areas Database, State of the Environment Directorate, Environment Canada.

Table 6.8

Target loads and guidelines for spring open lake concentrations of phosphorus in the Great Lakes

Basin	Target load (t/year)	Guidelines (µg/L)
Lake Superior	3 400	5
Lake Michigan	5 600	7
Lake Huron	4 300	5
Lake Erie	11 000	
Western basin		15
Central basin		10
Eastern basin		10
Lake Ontario	7 000	10

Note: Target loads are based on values considered necessary to achieve the concentration guidelines (column 3).

Source: Neilson et al. (1995).

dense populations of certain aquatic plants are found in these areas. In the past, local eutrophication, together with other organic and bacterial contamination, was also found in the St. Lawrence River downstream of municipal sewage discharges, especially downstream of the Island of Montreal. This has largely disappeared with the construction of sewage treatment plants (e.g., see Neilson et al. 1995).

In the St. Lawrence estuary, no evidence of eutrophication has yet been observed, even though it could occur locally in poorly flushed embayments where industrial or municipal sewage is released. Such areas are relatively rare because of the local topography and low population density. Strong water circulation in the main channel of the estuary eliminates the effects of nutrient enrichment, be it from local or upstream sources.

The high concentrations of phosphorus and algal blooms in lakes Erie and Ontario in the 1960s and early 1970s led, in 1972, to the original Great Lakes Water Quality Agreement (see Box 6.3) between Canada and the United States. This agreement and its 1978 revision committed the governments of Canada and the United States to reduce phosphorus loadings to the Great Lakes and the international portion of the St. Lawrence River (Table 6.8), to stop and reverse eutrophication and its effects in lakes Erie and Ontario, and to maintain lakes Huron and Superior as oligotrophic lakes. The main tools for achieving these goals were the reduction of phosphorus in detergents and a decrease in releases from sewage treatment plants and industrial sources. Since 1983, a reduction in nonpoint sources (from agricultural drainage and urban runoff) has also been a goal of the phosphorus control program.

Phosphorus loadings to the lower Great Lakes have been substantially reduced from the levels of the early 1970s. Total phosphorus loadings to lakes Erie and Ontario have been at or near the initial targets of 11 000 and 7 000 t a year, respectively, since the early 1980s, and

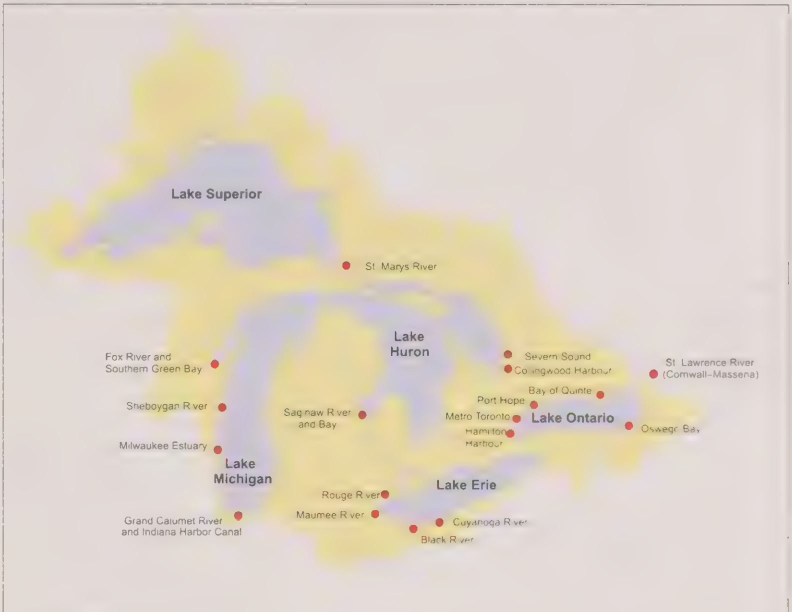
loadings to lakes Huron, Michigan, and Superior have generally been below their target levels since 1981. In lakes Erie and Ontario, concentrations of phosphorus (and of chlorophyll-a, a measure of algal biomass) in offshore waters have also declined (see Fig. 6.11) and are now below those expected from the load reductions. In the upper Great Lakes, phosphorus levels have remained below the proposed guidelines since the late 1970s (Neilson et al. 1995).

Average phosphorus concentrations in Lake Erie have declined by 60% from their levels in the late 1960s; year-to-year variations, however, are larger than in the other lakes (see Fig. 6.11), and in some years levels have exceeded target concentrations. Parts of the deepest central basin of Lake Erie still experience occasional anoxia (deficiency of oxygen) in late summer (Bertram 1993), but there is evidence that this may occur even in the absence of human-caused eutrophication (Reynoldson and Hamilton 1993).

By now, the open waters of Lake Ontario are tending towards restoration of oligotrophic conditions, and massive algal blooms in the offshore waters are rarely found anymore. High *Cladophora* levels, however, can still be found in the lower lakes (Howell 1996). The upper Great Lakes have maintained their oligotrophic status. Eutrophication continues to be a problem in many embayments: 18 Areas of Concern around the Great Lakes still report eutrophication or undesirable algae as a problem (see Fig. 6.10) (Environment Canada and U.S. Environmental Protection Agency 1995a).

On the other hand, the reduced flow of nutrients to lakes Erie and Ontario may not be compatible with current fisheries management policies and the stocking levels in these lakes (Jones et al. 1993). In Lake Ontario, stocking levels of trout and salmon have had to be cut back from 8 million a year in the early 1990s to 5 million in 1993 and 1994 to compensate for a reduced supply of the prey fish Alewife. This situation may be exacerbated by the fairly recent arrival and massive expansion of Zebra and Quagga mussels. These filter-feeders compete with zooplankton for available algae, with the effect of reducing the zooplankton food supply of Alewife. Another unintended side effect of reduced productivity and algal growth may be reduced sedimentation of toxic substances by algae and shifts in the food web leading to increased bioaccumulation of toxic substances (see the "Persistent toxic chemicals" section of this chapter).

Figure 6.10
Great Lakes basin Areas of Concern with respect to eutrophication or impairments related to undesirable algae



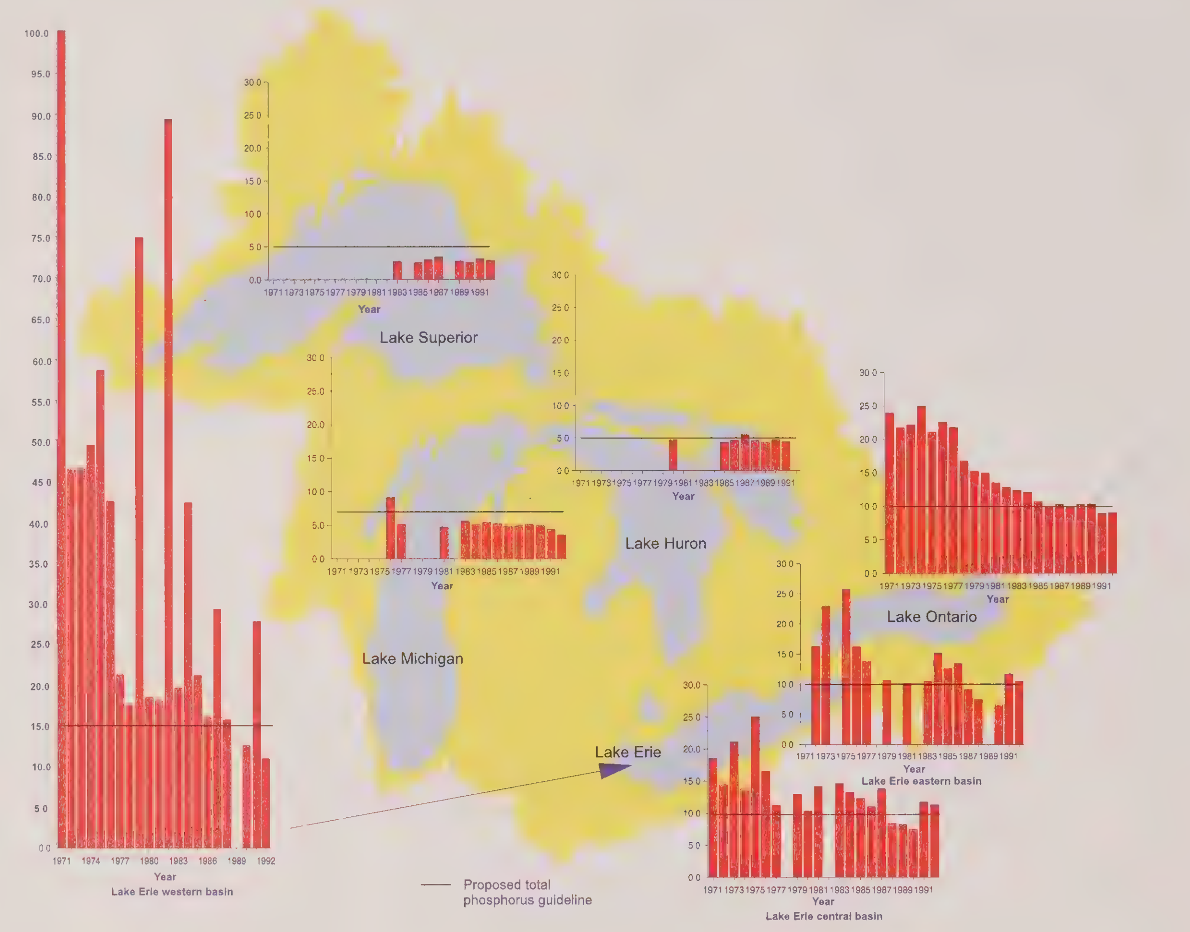
Source: Neilson et al. (1995).

Downstream in the St. Lawrence River, phosphorus concentrations have dropped significantly since 1979 as the loadings from Lake Ontario decreased and as sewage treatment plants were built in Montreal and elsewhere. However, nitrate levels have increased across the basin since the early 1970s. Atmospheric deposition in the upper Great Lakes and fertilizers, manure, and sewage elsewhere have been the main sources. At present, phosphorus levels are about 30–40 times lower than nitrogen (from nitrate plus nitrite) levels (Fig. 6.12). At this and lower phosphorus to nitrogen ratios, phosphorus, the less available nutrient, controls phytoplankton mass and lake productivity (Neilson et al. 1995). Therefore, nitrogen (from nitrate plus nitrite) is currently not a concern for eutrophication, nor is it yet a health concern, as present levels in surface water are still 10 times below the maximum acceptable concentration for drinking water. Levels are slowly increasing, however (see Fig. 6.12), and for this reason may warrant continuing monitoring.

Persistent toxic chemicals

For well over 300 years, the Great Lakes–St. Lawrence basin has been a centre for human settlement, agriculture, and manufacturing. The lakes and the St. Lawrence River have long been used to carry away the wastes that society generated. In this century, society produced large quantities of persistent toxic wastes, some of which accumulated in sediments, soil, groundwater, and aquatic biota. Because of the large surface area of the Great Lakes (roughly

Figure 6.11
Spring mean total phosphorus trends for open lake waters, 1971–1992



Note: Phosphorus concentrations are in µg/L.

Source: Neilson et al. (1995).

0.25 million square kilometres), direct deposition from the air also became an important route for toxic contaminants arriving from incinerators, smelters, and other sources. The slow flushing of most of the lakes (see the lake retention times in Fig. 6.1h) favours the retention of persistent, hydrophobic contaminants, and the long aquatic food webs have caused substantial biomagnification of contaminants in fish-eating birds and other top aquatic predators (Government of Canada 1991a). Top predators, such as the Bald Eagle, have higher levels of chemicals in their tissues than those in many other regions, and reproductive failures and birth defects were discovered earlier and received more attention in the Great Lakes than elsewhere in North America (Colborn et al. 1990).

The St. Lawrence River receives 40% of its contaminant load from the Great Lakes and additional loads from a number of industrial zones, urban centres, and tributaries along its length in the St. Lawrence lowlands. Water flows much faster through the river than through the lakes; as a consequence, accumulation of contaminants is less frequent and usually less severe. Contaminants adsorbed to particles are most likely found in the sediments of the slow-flowing sections of the river, whereas the more soluble contaminants are transported to the estuary and the gulf.

As of 1983, 362 contaminants (32 metals, 68 pesticides, and 262 other organic chemicals) had been reliably reported in the Great Lakes ecosystem, including the water, sediments, fish, other wildlife, and humans in and around the Great Lakes. The list includes 126 substances that can have acute or chronic toxic effects on life (Great Lakes Water Quality Board 1991). Eleven of these were selected in 1985 by the Great Lakes Water Quality Board of the IJC as critical pollutants (Table 6.9) because of their persistence, because of their ability to bioaccumulate in living organisms and cause adverse human and environmental health effects, and because they were already subject to extensive regulation (Great Lakes Water Quality Board 1985).

The revised Great Lakes Water Quality Agreement of 1978 (see Box 6.3) committed the governments of Canada and the United States to a policy in which "the discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated" from the Great Lakes and the international portion of the St. Lawrence River (Governments of the United States and Canada 1978).

Box 6.3
Great Lakes Water Quality Agreement

The Great Lakes Water Quality Agreement is probably the most influential binational agreement subsequent to the Canada–U.S. Boundary Waters Treaty of 1909. First signed in 1972, it covers all the Great Lakes and the international portion of the St. Lawrence River. Its primary purpose in 1972 was to stem and reverse eutrophication in the lower Great Lakes. In its revised (1978) and amended (1987) forms, the Great Lakes Water Quality Agreement focuses on persistent toxic chemicals and commits Canada and the United States "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." Some specific commitments under the agreement that are of particular importance for the management of toxic substances in the Great Lakes are:

- *the virtual elimination of persistent toxic substances;*
- *development of Remedial Action Plans (RAPs) for nearshore Areas of Concern (AOCs) and of Lakewide Management Plans (LaMPs) for each of the Great Lakes (see Box 6.4);*
- *monitoring to assess progress and trends and to detect new problems (e.g., to resolve the question of atmospheric deposition of toxic substances); and*
- *determination of mass balances of persistent toxic substances, and the study of their effects.*

The role of the IJC is to monitor progress, provide advice to the parties to the agreement, distribute information, and provide a public forum for consultation. The IJC has been particularly influential through its biennial meetings and reports and through its advisory boards (Water Quality Board, Air Quality Board, Science Advisory Board, Council of Great Lakes Research Managers). The governments of Canada and Ontario concluded the Canada–Ontario Agreement in 1994 to jointly fulfil Canada's responsibilities under the agreement.

Under the 1994 Canada–Ontario Agreement Respecting the Great Lakes Basin Ecosystem, the use, generation, and release of the 11 IJC critical pollutants, plus chlordane and octachlorostyrene, are targeted for virtual elimination in a first phase, or Tier I; 26 additional substances are selected for virtual elimination in Tier II (Canada–Ontario Agreement 1994). In the near term, the agreement commits to:

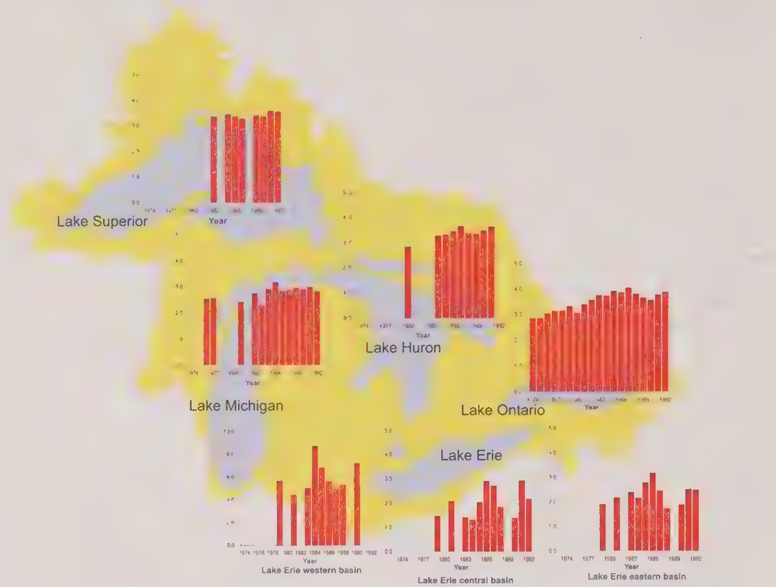
- zero discharge for five organochlorine pesticides;
- decommissioning 90% of the high-level polychlorinated biphenyls (PCBs) and destruction of 50% of those in storage; and
- 90% reduction of the remaining seven substances.

To implement new provisions of the 1987 amendments to the Great Lakes Water Quality Agreement, the federal government announced, in 1988, the Great Lakes Action Plan, followed in 1994 by the Great Lakes 2000 Program. One component of these programs, the Clean-up Fund, is applied to the Areas of Concern under Canadian jurisdiction. Projects are undertaken as partnerships with the private sector and focus on contaminated sediments, problems caused by sewage treatment, combined storm sewer overflow, and creating wildlife habitats in degraded areas.

Under the St. Lawrence Action Plan of 1988 (see Box 6.2), priority polluting industrial plants were selected for the Quebec portion of the river. Many of the chemicals discharged by these plants are also of concern in the Great Lakes, but metals such as cadmium, chromium, and copper and additional organochlorines and nonorganochlorine pesticides (e.g., atrazine) were also considered (Governments of Canada and Quebec 1993). The St. Lawrence Action Plan committed the federal government and the province of Quebec to a 90% reduction in the loadings of toxic chemicals from the 50 most polluting industrial plants into the river. By the 1993 target date, effluent from the 50 plants had been reduced by almost 75%. One of the objectives of St. Lawrence Vision 2000 (the second St. Lawrence Action Plan), to be achieved by 1998, is the reduction of liquid toxic effluents and virtual elimination of discharges of persistent toxic chemicals (see Box 6.2).

The governments of Canada and the United States have drafted a virtual elimination strategy that sets forward a collaborative process that involves all sectors of society. To achieve the virtual elimination of a toxic substance, one must know the amounts of the substance entering and leaving the ecosystem and its concentrations and behaviour in the different compartments (water, sediment, biota) of the system (IJC 1993). This type of information for a few substances

Figure 6.12
Spring mean nitrate-plus-nitrite trends for open lake waters, 1968–1992



Note: Mean nitrate-plus-nitrite concentrations are in µg/L.

Source: Environmental Conservation Service, Environment Canada; Great Lakes National Program Office, U.S. Environmental Protection Agency.

is presented in the rest of this section. The emphasis is on PCBs and mercury, for which the available information is most extensive. PCBs are of special concern in the Great Lakes because they are strongly implicated in birth defects and reproductive failures of fish-eating birds and other species. For this reason, a brief discussion of environmental effects is also included. PCBs also provide insight into the likely behaviour of the other persistent toxic organochlorine substances listed in Table 6.9. For more information on these other chemicals, see De Vault et al. (1995) and the original references cited therein.

Sources and fates of toxic contaminants in the Great Lakes and the St. Lawrence River

The IJC (1993) identified the following as the main sources of persistent, bioaccumulative toxic substances to the Great Lakes and the St. Lawrence River:

- industrial and municipal discharges (effluent and sewage);
- leachates from industrial and municipal landfills, primarily via groundwater;
- urban and agricultural runoff (including storm sewer and sewer overflow);
- outflow from an upstream lake or tributary streams;
- the atmosphere;
- spills from ships and nearshore accidents; and
- industrial spills.

Resuspension of contaminated sediments is another important source of these toxic substances (whereas sedimentation of sediments is a removal process).

During the early stages of pollution control (St. Lawrence Action Plan) and virtual elimination (Great Lakes Action Plan), attention was directed towards point sources, such as direct discharges from municipal and industrial pipes, because they were easily identified and were simple and least costly to control. In the Great Lakes, the most serious of these point sources are found in the Areas of Concern (Fig. 6.13), all of which contain contaminated sediments (Hartig and Law 1994). Along the St. Lawrence, attention was focused on the effluents of the 50 most polluting industrial plants. The most contaminated sediments (Fig. 6.14) were found in the fluvial lakes downstream from these industries and those of the last Area of Concern at Cornwall–Massena.

Considerable progress has been made in reducing discharges from point sources. Waste and sewage treatment systems have been constructed, and some substances have been restricted. For instance, PCBs are being phased out, lead in gasoline has been banned, and mercury is being restricted. Discharges of other chemicals have been limited, in some cases by changing manufacturing processes to prevent their release. Contaminated sediments in some Great Lakes Areas of Concern have been or are being removed, and plans for removal have been drawn up in others (J. Hartig, IJC, personal communication). The quantity of toxic chemicals discharged from the 50 industrial plants along the St. Lawrence has also been reduced by almost 75% since 1988 (Governments of Canada and Quebec 1993).

As point sources are increasingly controlled, attention has turned to loadings from the atmosphere, groundwater, and field runoff. These loadings are often impossible or prohibitively expensive to measure directly, so scientists use a combination of regional or continental emissions inventories, measured air and water concentrations, knowledge of the properties of chemicals, and models to understand the relative contributions from the different sources. Resulting estimates of the loadings of PCBs and mercury to and their elimination from lakes Ontario and Superior (and the Quebec portion of the St. Lawrence River, for PCBs only) are shown in Table 6.10. Table 6.11 shows the relative magnitudes of air and water loadings of dioxins and furans to the Great Lakes, and, to illustrate the continent-wide origins of these extremely toxic com-

Table 6.9

List of the 11 IJC critical pollutants: sources, guideline concentrations, and reasons for concern

Substance	Sources and uses	Water quality objectives (ppb)[a]	Guidelines for fish (ppb)[a]	Main causes of concern
PCBs (209 related chemicals)	Insulating fluid in transformers, hydraulic fluid, lubricant; widely used until late 1970s; new uses restricted, but major disposal problems remain	0.001	2	Birth defects, reproductive failures, hormone mimicry
DDT and its breakdown products, including DDE	Insecticide now banned in Canada and United States; still used in tropical countries (malaria control)	0.003	5	Reproductive failures (eggshell thinning)
Aldrin and dieldrin	Insecticide	0.001	NG	Reproductive failure
Toxaphene (hundreds of related chemicals)	Insecticide; banned in Canada and the United States; used in Central America	0.008	NG	Acute fish toxin, carcinogen
2,3,7,8-TCDD (tetrachlorodibenzo-p-dioxin)	Waste by-product of combustion and some industrial processes using chlorine, e.g., pulp and paper chlorine bleaching; and from chlorophenol production	DL	20 ppt	Endocrine disruption, suppression of immune system
2,3,7,8-TCDF (tetrachlorodibenzofuran)	Same as dioxins	NG	NG	Same as dioxins, less toxic
Mirex	Pesticide, industrial chemical for fire retardation; no longer used	DL	0.1	Reproductive effects, cancer
Mercury	Formerly used in paints and electrical equipment; released during coal combustion; formerly used in pulp and paper production (chlor-alkali process, slime prevention)	0.2	0.5	Nervous system disorders
Benzo(a)pyrene, representative of polycyclic aromatic hydrocarbons (PAHs); one of the most carcinogenic PAHs	By-product of incomplete combustion: incineration, steel, coke, and aluminum production, coal liquefaction and gasification, wood stoves, etc.	0.01	NG	Tumour induction in fish, particularly liver tumours
Hexachlorobenzene (HCB)	Pesticide, by-product of the manufacturing of other pesticides and carbon electrode processes; combustion by-product	NG	NG	Interference with enzymes, endocrine disrupter, cancer
Alkylated lead	Gasoline additive (banned in 1988)	10–25[b]	NG	Neurotoxin, immunotoxin

Note: Tier I pollutants identified for virtual elimination under the Canada–Ontario Agreement include these 11 IJC pollutants plus all other chlorinated dioxins and furans, chlordane (a pesticide), and octachlorostyrene, a by-product from high-temperature industrial processes involving chlorine.

[a] Fish guidelines are health protection guidelines from Health Canada, as reported in De Vault et al. (1995). Water quality objectives are from the 1978 Great Lakes Water Quality Agreement and are for unfiltered water samples, with the exception of mercury. DL means less than detection levels as determined by the best available scientific methodology (Government of Canada 1991a). NG indicates no official guideline was listed.

[b] Concentration depends on the lake, with the lower lakes having higher objectives than the upper lakes.

Source: Government of Canada (1991a); IJC (1993); De Vault et al. (1995).

pounds, Figure 6.15 shows source regions for loadings to Lake Ontario of a typical compound in this family (2,3,7,8-pentachlorofuran).

Water loadings are a larger fraction of the total in the St. Lawrence than in the Great Lakes. The contribution of different sources to these loadings has been investigated in the St. Lawrence Action Plan. Results are shown in Table 6.12. The data show the Great Lakes and the international portion of the St. Lawrence (upstream) and tributaries as major sources, whereas the priority industrial plants were the source of a limited number and quantity of pollutants. Much of the tributary load is thought to come from distributed (e.g., agricultural) sources. Some tributaries, such as the Tortue River, are the source of pesticides such as atrazine and diazinon to the small La Prairie basin and the St. Lawrence River (Asseau–INRS 1992).

Many of the reported loadings (see also De Vault et al. 1995) are crude estimates, in particular the numbers for air loadings and volatilization. Nonetheless, they allow some general conclusions about the sources and fate of persistent toxic chemicals in the Great Lakes–St. Lawrence basin:

- Wet and dry deposition of contaminated particles are important sources of contaminants to all Great Lakes (Tables 6.10 and 6.11). In Lake Superior (whose shores and drainage basin are pristine compared with those of the other lakes), air deposition is the predominant source of contamination by dioxins and mercury and is at least as important as a source of PCBs as all other sources combined (this excludes consideration of vapour deposition, listed below; see Tables 6.10 and 6.11).
- Deposition of the vapour form of volatile contaminants (e.g., PCBs or mercury) is another important route for the entry of these contaminants into the Great Lakes. Simultaneously, however, contaminants already in the water volatilize into the air and leave the lake. Which process predominates at any time depends on the relative concentrations of the contaminant in the air and in the water. For PCBs and mercury, models (combined with air and water concentrations measured between 1986 and 1992) predict that volatilization is by far the more important process. In fact, volatilization

Figure 6.13
The 43 Areas of Concern in the Great Lakes basin, 1991

Lake Superior

1 Peninsula Harbour
2 Jackfish Bay
3 Nipigon Bay
4 Thunder Bay
5 St. Louis Bay/River
6 Torch Lake
7 Deer Lake-Carp Creek/River

Lake Michigan

8 Manistique River
9 Menominee River
10 Fox River/Southern Green Bay
11 Sheboygan River
12 Milwaukee Estuary
13 Waukegan Harbor
14 Grand Calumet River/Indiana Harbor Canal
15 Kalamazoo River
16 Muskegon Lake
17 White Lake

Lake Huron

18 Saginaw River/Saginaw Bay
19 Collingwood Harbour
20 Severn Sound
21 Spanish River Mouth

Lake Erie

22 Clinton River
23 Rouge River
24 River Raisin
25 Maumee River
26 Black River
27 Cuyahoga River
28 Ashtabula River
29 Presque Isle Bay
30 Wheatly Harbour

Lake Ontario

31 Buffalo River
32 Eighteen Mile Creek
33 Rochester Embayment
34 Oswego Bay
35 Bay of Quinte
36 Port Hope
37 Metro Toronto
38 Hamilton Harbour

Connecting channels

39 St. Marys River
40 St. Clair River
41 Detroit River
42 Niagara River
43 St. Lawrence River (Cornwall–Massena)

Note: Collingwood Harbour (#19) has completed remediation and has been delisted by Canada and Ontario.

Source: Great Lakes Water Quality Board (1991).

is now thought to be the major route by which volatile contaminants such as PCBs and mercury leave the lakes (Table 6.10; see also De Vault et al. 1995).

- Upstream lakes and connecting rivers are a large source of contaminants. For example, Lake Michigan is the main source of atrazine to northern Lake Huron (Schottler and Eisenreich 1994), the Niagara River is the predominant source of chemicals such as PCBs, mercury, atrazine, and (probably) dioxins to Lake Ontario (Tables 6.11 and 6.12; Schottler and Eisenreich 1994), and 40% of the load to the Quebec portion of the St. Lawrence is estimated to come from upstream (Table 6.12).
- Both local sources within the basin and external sources outside the basin are important contributors of toxic contaminants to the Great Lakes ecosystem. Dioxins, furans, dichlorodiphenyltrichloroethane (DDT), and possibly toxaphene appear to have important sources as far away as the southern United States and Mexico (see Fig. 6.15; Cohen et al. 1995). The sources of other, more volatile pollutants such as hexachlorobenzene are even further away, of worldwide origin. Only a few types of continent-wide sources, in particular medical waste incinerators (48%), are major contributors to the dioxins and furans in the Great Lakes; others include municipal waste incinerators (22%), iron ore sintering plants (8%), and cement kilns burning hazardous wastes (8%) (Cohen et al. 1995).

Levels and trends in concentrations

Water, sediments, and air

Concentrations of PCBs in the water column have been known for Lake Superior since 1978 and for Lake Michigan since 1980. Data for other lakes are more recent but may be expected to follow a similar

Figure 6.14
Contaminated zones in the St. Lawrence

Note: Hg = mercury; PAH = polycyclic aromatic hydrocarbons; PCB = polychlorinated biphenyls.
Source: Adapted from Frenette et al. (1989).

pattern. A sharp decrease from the early concentrations has been observed, but the decrease has slowed down in recent years (see, for example, data for Lake Superior in Fig. 6.16; De Vault et al. 1995). This trend parallels that found in the biota (fish and Herring Gull eggs) for all the lakes (see below). As the rate of decrease is proportional to the remaining concentrations, such a slowdown may in fact be expected (Jeremiason et al. 1994). Another explanation for the slowdown is a change in the food web of the lakes, which may lead to a (temporary) slowdown (De Vault et al. 1995). Figure 6.17 shows concentrations of several PCB congeners, as well as DDT breakdown products, mirex, hexachlorobenzene, and heavy metals, in the sediments of Lake St. Francis. Because of possible differences in sampling and analysis (particularly for PCBs), the Great Lakes and St. Lawrence data are not directly comparable.

Concentrations of PCBs and other volatile contaminants in air are the basis for the estimates of air loadings to the lakes. They are relatively uniform across the Great Lakes basin except near some urban areas (De Vault et al. 1995). The most striking example of urban influence is the almost 10-fold increase from the upper to the lower end of Lake Michigan (S.J. Eisenreich, University of Minnesota, personal communication, as reported in De Vault et al. 1995). Data on air levels, however, are quite limited. In 1988, a systematic air monitoring program was established (the Integrated Atmospheric Deposition Network). Data are now becoming available for the deposition of organochlorines, metals, and polycyclic aromatic hydrocarbons (PAHs).

Biota

Levels of contaminants in Spottail Shiners, Snapping Turtles (both nearshore species with limited home range), and caged clams are good indicators of local contamination. Measurements at different locations (Suns et al. 1993) show that the Niagara River

Table 6.10

Estimated air and water loadings of PCBs and mercury to lakes Superior and Ontario and of PCBs to the St. Lawrence River, 1991–1992

	PCB loadings (kg/year)			Mercury loadings (kg/year)	
Loadings	Lake Superior	Lake Ontario	St. Lawrence River (Quebec portion)	Lake Superior	Lake Ontario
Water loadings					
Industry	10	4	19	39	12
Runoff	18	83		40	29
Combined sewer overflow	2	4		3	2
Municipal sewage treatment plants	8	15		34	89
Spills				2	
Other sources			26		
Sum of direct discharges	38	107	45	119	132
Monitored and unmonitored tributaries	140	64	12	124	94
Connecting channels and upper lakes	N/A	354	29	N/A	2 250
All water loadings	178	525		243	2 476
Air loadings					
Wet and dry deposition	85	64		810	Not known
Net gas exchange	–1 680	–440		–175	Not known
Total loadings before outflow and sedimentation	–1 417	148	86	878	Not known

Notes: 1. Some data (e.g., direct discharges) may refer to earlier years.
2. Tributary loadings for Lake Ontario are low estimates, based on partial monitoring (three of the four seasons and not all tributaries in the Lake Ontario drainage basin).
3. Air loadings have very high uncertainties: ± 51%, 110%, and 150% for wet and dry deposition and net gas exchange of PCBs in Lake Ontario, respectively (Hoff et al. 1996); the level of uncertainty for Lake Superior is indicated in Table 6.15.
4. Amounts of total PCBs are determined by measuring certain congeners and calculating total PCBs according to a formula; "total PCBs" for the St. Lawrence is based on 13 congeners; "total PCBs" based on different measured congeners may only be approximately comparable.
5. Mercury data for the St. Lawrence were not available.
6. "Industry" for the St. Lawrence includes only the 50 targeted industrial plants; "connecting channels and upper lakes" includes all contributions from the Great Lakes and the international portion of the St. Lawrence; "other sources" in the St. Lawrence is determined by difference (exports to estuary less industry, tributaries, upper lakes, and connecting channels); it thus includes all the other categories in the table (runoff, sewers, municipal, as well as air loadings).

Sources: *Lake Ontario*: Direct discharges of PCBs from Thompson (1992); contributions of PCBs from connecting channels and tributaries from Strachan et al. (1995); air data for PCBs from Hoff et al. (1996); all mercury data from Thompson (1992); *Lake Superior:* PCB data from Table 6.15 and sources given in that table; water data for mercury from Dolan et al. (1993); air data from Hoff et al. (1996); *St. Lawrence River*: St. Lawrence Centre (1996a).

and the Cornwall–Massena stretch of the St. Lawrence River are highly contaminated and are likely sources of contamination in Lake Ontario and downstream sections of the St. Lawrence, respectively. Data from chironomids, a bottom-dwelling insect, show that contamination of bottom sediments causing impairments occurs in 38 Areas of Concern.

Contaminants in fish from the open waters of the Great Lakes and in eggs from fish-eating birds (Herring Gulls) have been monitored since the mid-1970s, providing one of the most extensive databases on trends in environmental contaminants (Pettit et al. 1994a, 1994b). Such monitoring programs were originally implemented because direct measurement of the minute quantities found in water was not technically feasible at the time. Fish and fish-eating birds, on the other hand, bioaccumulate and biomagnify toxic contaminants. PCBs in Herring Gull eggs can be 10 million times more concentrated than in water. Contaminant levels in biota are excellent indicators of contaminant trends in aquatic ecosystems.

The highest contaminant concentrations in aquatic biota and fish-eating species from the Great Lakes likely occurred in the period before monitoring programs were established. Table 6.13 and Figure 6.18 show the maximum recorded and the 1992 concentrations of certain persistent toxic substances in Herring Gull eggs, top predator fish (Lake Trout and Walleye), and Rainbow Smelt in the Great Lakes. Figure 6.19 illustrates trends in PCB concentrations in Lake Trout/Walleye since the late 1970s or early 1980s. Since 1985, the levels of PCBs, DDT, dieldrin, hexachlorobenzene, toxaphene, and benzo(a)pyrene in Herring Gull eggs and fish have not declined significantly for any of the Great Lakes (De Vault et al. 1996; Fig. 6.19).

These data illustrate some important trends:

- Historically, fish and the eggs of fish-eating birds from lakes Michigan and Ontario contained, in general, much higher body burdens of persistent toxic contaminants than those from the other Great Lakes (Table 6.13). This geographic pattern persists in more recent data, although concentrations are much lower (Fig. 6.18).
- Measured concentrations of persistent toxic substances in fish and fish-eating birds were highest in the 1970s and have declined since then. Although direct measurement data prior to the implementation of the monitoring programs are not available, retrospective analysis of archived samples of fish and eggs suggests that levels were higher in the 1960s.
- The rate at which concentrations in biota are decreasing has slowed or even stopped altogether since the mid-1980s. Small increases in the levels of contami-

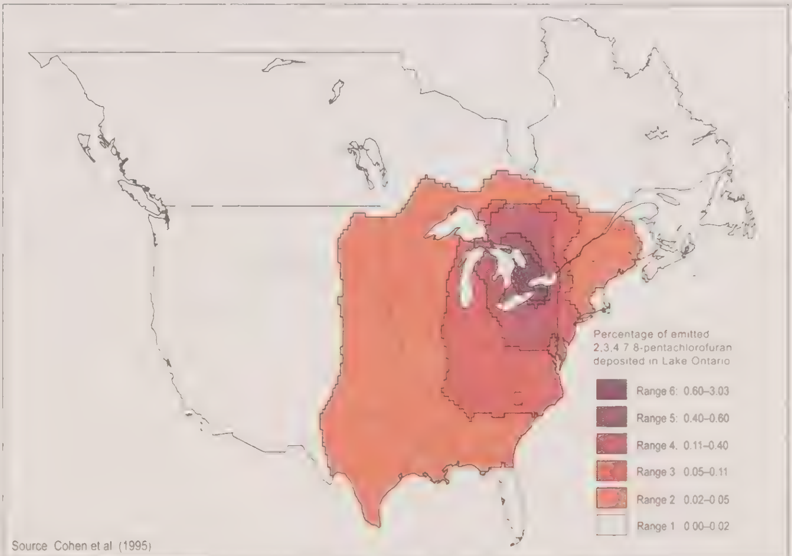
Table 6.11
Estimated loadings of dioxins and furans to the Great Lakes

Lakes	Loadings (g/year TEF)		
	Air	Water	Total
Superior	5.6	1.4	7.0
Michigan	13.7	1.9	15.6
Huron	8.6	1.4	10.0
Erie	7.3	11	18.3
Ontario	6.4	>3.9	>10.3
All lakes	42	>20	>61.2

Notes: 1. g/year TEF is the amount of measured types (congeners) of dioxins and furans expressed in units of 2,3,7,8-TCDD (g/year) of equivalent toxicity.
2. Water loadings to Lake Ontario are higher than indicated because Niagara River input is unknown.
3. Air loadings are from sources across the continent, whereas water loadings are from regional sources.

Source: Cohen et al. (1995).

Figure 6.15
Contribution to Lake Ontario loadings of 2,3,4,7,8-pentachlorofuran emitted from different regions of North America



nants in some species in some locations (e.g., Coho Salmon in Lake Michigan) have even been found. There are indications that a change in the food web might be responsible for these most recent trends (see the discussion in De Vault et al. 1995 and the original references therein). If this hypothesis is correct, concentrations may begin to decline again once the food web restabilizes. It has also been suggested that contaminant levels may be reaching a new steady state at levels lower than those of the 1970s but higher than background levels. Sediment resuspension of toxic substances continues to occur basin-wide.

Advisories for the consumption of fish issued by provincial and state governments are useful indicators of concentrations of toxic contaminants. However, different advisories are issued at different concentrations in different jurisdictions; thus, comparisons across jurisdictional boundaries are ambiguous at best. In Ontario, advisories are based on the levels of five contaminants: 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) (20 parts per trillion, or ppt), DDT and its metabolites (5.0 parts per million, or ppm), PCBs (2.0 ppm), mirex (0.1 ppm), and mercury (0.5 ppm). Restricted consumption of Lake Trout is being advised for all lakes and of several other species in 36 of the Areas of Concern. Advisories for the consumption of salmon and Lake Trout are mostly due to high levels of PCBs (and mirex or mercury in Lake Ontario), whereas those for inshore species are often caused by high mercury concentrations (Ontario Ministry of the Environment and Ontario Ministry of Natural Resources 1992).

In the St. Lawrence, known impacts of high concentrations of toxic chemicals are rare and localized (Fig. 6.20). Most common are restrictions on drinking water and commercial fishing and advisories for the consumption of fish. Mercury in top predator fish has been the most frequent cause for such restrictions. In the 1970s, when concentrations of mercury were highest, the commercial fishery was greatly disrupted by the closure of the Walleye and Northern Pike fishery upstream of Trois-Rivières. There are some signs of improvement, as mercury levels in Northern Pike and Yellow Perch in Lake St. Francis declined significantly between 1976 and 1988 (Laliberté 1992). However, fish consumption advisories are still in effect for several sections of the St. Lawrence and certain species of predator fish.

Contaminants are also transported into the St. Lawrence estuary, where they bioaccumulate in top predators such as Belugas (see "The Beluga" section, below). Most of the critical pollutants on the IJC list have been found at high concentrations in the fatty tissues of these whales. American Eels migrating from Lake Ontario are thought to

Table 6.12

Estimated loadings of contaminants to the St. Lawrence River, by source

Contaminants	Great Lakes and international portion of river (%)	Tributaries (%)	Priority industries (%)	Other sources (%)	Total (kg/year)[a]
Organic substances					
Atrazine	58	10	0	32	2 654
Benzene hexachloride	56	44	0	0	18
Chlordane	71	26	0	3	97
DDT	57	42	0	1	284
Diazinon	39	31	0	30	1 799
Hexachlorobenzene	91	73	0	0	11
PAHs	26	22	3	49	8 676
PCBs	34	14	22	30	86
Pentachlorophenol	26	27	1	46	291
2,3,4,6-Tetrachlorophenol	25	31	0	44	71
Metals					
Cadmium	39	31	28	2	10 678
Chromium	54	24	22	0	672 891
Cobalt	38	26	1	35	114 768
Copper	25	24	5	46	674 496
Lead	32	52	2	14	160 710
Nickel	63	21	8	8	563 314
Zinc	58	44	34	–36[b]	1 030 005
Total toxic contribution[c]	**42**	**29**	**9**	**20**	

[a] Measured as output to estuary.
[b] Number calculated from the difference between inflow and outflow; negative value reflects uncertainties in the data for zinc rather than a real negative for "other sources."
[c] Estimated from the "Chimiotox Index," which is calculated from the amounts of the substance weighted by its toxicity (see source for explanation).

Source: St. Lawrence Centre (1996a, 1996b).

be the source of all the mirex and up to 50% of other toxic chemicals in the whales (Béland et al. 1993).

Effects

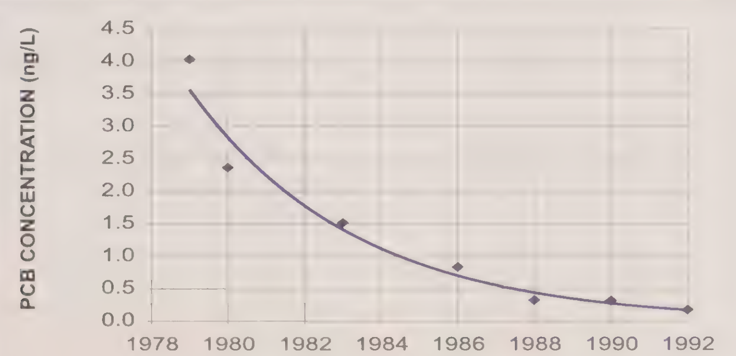
In the 1960s, breeding failures and congenital abnormalities such as crossed bills, club feet, and missing eyes were noted among colonies of Herring Gulls and other fish-eating birds on the shores of the Great Lakes. These effects were subsequently linked to the presence of persistent organochlorine contaminants in the birds' tissues (National Research Council of the United States and Royal Society of Canada 1985). Occurrences tended to be most severe near the most heavily contaminated areas, such as Saginaw Bay, Hamilton Harbour, and the Detroit River (Fox 1993). Table 6.14 summarizes some of the effects of persistent toxic chemicals that have been reported in 11 wildlife species around the Great Lakes.

PCBs are thought to be the main chemicals responsible for reproductive failures, birth defects, and neurological effects in various species, and DDT has been linked to eggshell thinning and reduced reproductive success in Bald Eagles and other fish-eating birds (Colborn et al. 1990). PAHs have been associated with tumours in certain fish from Hamilton Harbour and other heavily industrialized areas (Baumann et al. 1987, 1990). Toxic chemicals are also considered as one possible explanation for the low reproductive success of Lake Trout in lakes Ontario and Michigan (see the "Fisheries" section of this chapter). However, effects of toxic chemicals are less clear for fish than for other wildlife. Many fisheries scientists do not believe that the concentrations of persistent toxic chemicals are high enough at present to be the sole or main cause of the lack of Lake Trout recruitment in these lakes (Fitzsimons 1995).

The main effects of organochlorine contaminants are now thought to occur in the offspring of exposed individuals across a variety of species (Bishop et al. 1991; Wren 1991; Fox 1993), including humans. The observed effects in various species are thought to be the result of the ability of organochlorines and some other chemicals to modulate, mimic, or block activity of naturally occurring estrogen and androgen hormones (Colborn and Clements 1992; Colborn et al. 1993). Contaminants are transferred from the mother, and effects can occur in the womb. Subtle effects have been reported in children whose mothers consumed large amounts of Great Lakes fish before the children were born (see the section on "The environment and human health" in this chapter; Jacobson and Jacobson 1993). These chemicals are suspected to interfere especially with the developing endocrine, immune. and nervous systems of the fetus and its sexual differentiation. In controlled experiments with laboratory animals, exposure to PCBs resulted in undeveloped sex organs, characteristics of the opposite sex (feminized males and masculinized females), and altered sexual behaviour at maturity — effects similar in type to those observed in the environment.

Figure 6.16

Decrease in PCB concentrations in the water column of Lake Superior, 1979–1992



Notes: 1. All data for 82 congeners.
2. Pre-1990 converted to value for 82 congeners.
3. Trend line shows pseudo-first-order decline.

Source: Jeremiason et al. (1994).

Risk management in the face of uncertainty: the weight-of-evidence approach and persistent toxic chemicals in the Great Lakes

Risk management is a process by which society, through its decision-makers, judges how grave or acceptable it considers a particular risk and what it is willing to do to avoid it. Traditionally for toxic chemicals, the process was formalized (and thus made predictable) by specifying a level for a single chemical that would cause an unacceptable risk (often one occurrence of cancer in a million) and thus trigger action. That level was determined by prescribed scientific methods of risk assessment (epidemiological surveys and studies and toxicological laboratory experiments; Great Lakes Science Advisory Board 1995) and socioeconomic considerations. Decisions were made largely by government officials on the advice of technical experts. Value judgements were implicit and not usually open to public scrutiny.

This approach poses difficulties where populations and species are exposed to mixtures of persistent toxic chemicals and where these chemicals are suspected to cause complex intergenerational effects. Accepted protocols for a traditional risk assessment of such effects are often not available and, in any case, would be exceedingly difficult and time-consuming

Table 6.13
Maximum recorded concentrations of some persistent toxic substances in biota from the Great Lakes

	Maximum concentrations (ppm or ppt wet weight)[a]			
	PCBs (ppm)	Total DDT (ppm)	TCDD[b] (ppt)	Mercury (ppm)
Lake Superior				
Herring Gull eggs	75 (1975)	22.8 (1975)	79 (1981)	
Lake Trout	1 (1984)	0.4 (1981)	<20	0.29 (1980)
Rainbow Smelt	1 (1988)	0.086 (1982)		0.1 (1981)
Lake Michigan				
Herring Gull eggs	120 (1976)	33.3 (1976)	60 (1981)	
Lake Trout	22.9 (1974)	19.1 (1970)	20–60	
Rainbow Smelt				
Lake Huron				
Herring Gull eggs	70 (1974)	17.1 (1974)	62.5 (1982)	
Lake Trout	2 (1981)	0.93 (1981)	20–40	0.22 (1981)
Rainbow Smelt	0.28 (1982)	0.11 (1982)		0.07 (1980)
Lake Erie				
Herring Gull eggs	70 (1974)	7.5 (1977)	32 (1984)	
Lake Trout	1.43 (1990)	0.57 (1989)	<20	0.19 (1980)
Rainbow Smelt	0.75 (1988)	0.15 (1989)		0.05 (1977)
Lake Ontario				
Herring Gull eggs	150 (1974)	22.9 (1975)	947 (1974)	
Lake Trout	8.2 (1977)	4.28 (1977)	53.1 (1988)	0.22 (1983)
Rainbow Smelt	2.1 (1988)	0.6 (1977)		0.091 (1980)

Notes: 1. Lake Trout data are for fish 4+ years old, and Lake Erie data refer to Walleye.
2. Lake Michigan Lake Trout data are from the U.S. Environmental Protection Agency and consist of composite samples of 10 fish, each 600–700 mm in length.
3. DDT data for Herring Gull eggs are for p,p'-DDE, a metabolic breakdown product of DDT.
4. Herring Gull dioxin data are from eggs sampled in the following colonies: Scotch Bonnett – Lake Ontario; Port Colborne Lighthouse – Lake Erie; Chantry Island – Lake Huron; Gull Island – Lake Michigan; and Agawa Rock – Lake Superior.

[a] Years given in parentheses.
[b] TCDD = 2,3,7,8-tetrachlorodibenzo-p-dioxin.

Source: De Vault et al. (1995); Department of Fisheries and Oceans; Canadian Wildlife Service, Environment Canada.

to carry out. In 1992, the IJC recommended that a broader approach be used for decision-making and risk management of persistent toxic substances in the Great Lakes (IJC 1992), arguing that the potential for damage might be so severe and the damage so difficult to reverse that a faster approach was needed for dealing with the considerable uncertainties. This approach, called "weight of evidence," would make use of all methods traditionally used in scientific consensus-building, as well as "civic science," which includes ethical and other public values (Great Lakes Science Advisory Board 1995). The Canadian and U.S. governments have accepted in principle the recommendation that the weight-of-evidence approach be used for toxic substance management in the Great Lakes.

The weight-of-evidence approach, although potentially faster in the face of uncertainty, includes the values and judgements of those who do the weighing. The results are less predictable than in the traditional approach and depend on the constituency that does the weighing, how broad a spectrum of values is considered, and how the weighing group reaches its consensus (an essentially political process). A recent example, where different groups put different weight on the same evidence, is the question of a ban on chlorine as an industrial feedstock in the Great Lakes basin. Many environmental organizations and some scientists favour such a ban, and in 1993 the IJC recommended a chlorine ban to the two national governments. The governments, in their own weight-of-evidence approach, concluded that a complete ban could not be supported by scientific evidence but that a number of dangerous substances should be eliminated.

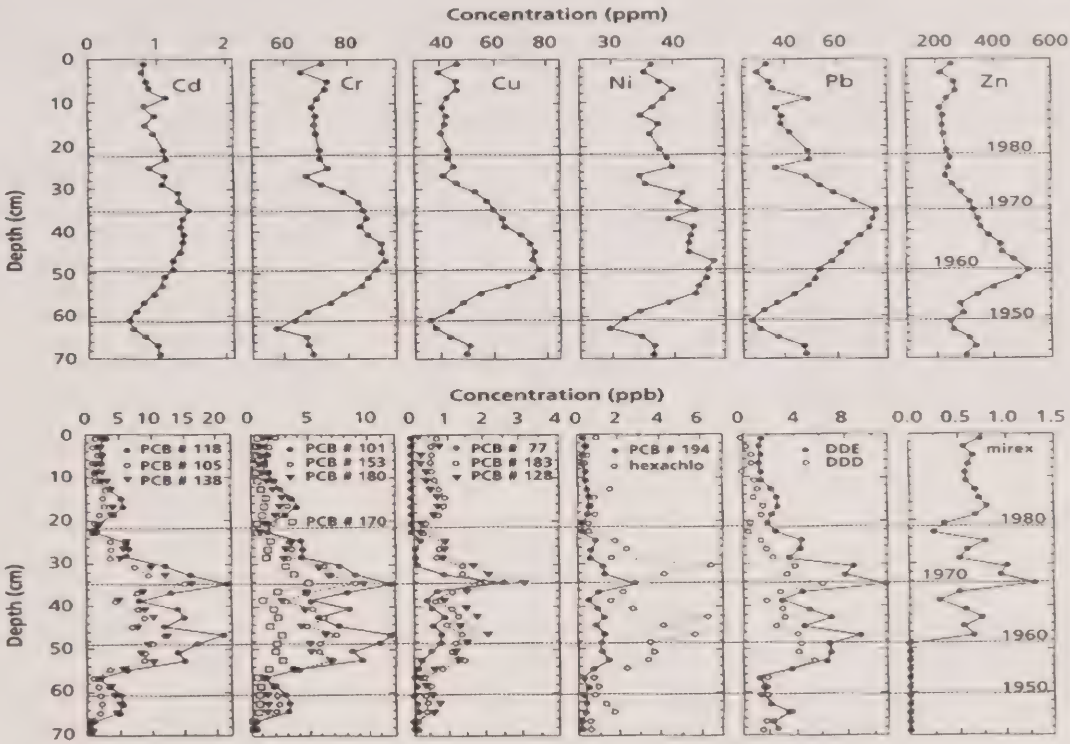
The 1994 Chlorinated Substances Action Plan undertakes to use regulatory and non-regulatory tools to eliminate the most harmful chlorinated substances, including carbon tetrachloride, methyl chloroform, perchlorethylene, 10 Canada–Ontario Agreement Tier I substances targeted for virtual elimination (see Table 6.9), and short-chain chlorinated paraffins. In addition, performance agreements have been negotiated with the automotive, dry cleaning, plastics, printing, and graphics industries and the importers of chloranil-based dyes and pigments.

Another instance in which a broad political consensus based on weight of evidence will probably be required is the control of toxic substances transported over long distances through the air. A continental or even global constituency is involved, the perception of risk varies from one group to the next, and the contribution of pollutants from sources in one region to loadings in another is highly uncertain. As of this writing, member countries of the United Nations are developing a protocol for persistent organic pollutants in an effort to meet this challenge.

Air pollution in the Windsor–Quebec City corridor: the price of the automobile?

One of the principal air quality issues in the Windsor–Quebec City corridor involves ground-level ozone and the numerous other contaminants of smog. Ground-level ozone is created from nitrogen oxides (NOx) and volatile organic compounds (VOCs), such as gasoline vapours (see Chapters 10 and 12 for more information). In sunlight, these gases react with one another to form ozone and other oxidizing substances. Origins of these

Figure 6.17
Concentrations of some persistent toxic contaminants in the sediments of Lake St. Francis



Note: Cd = cadmium; Cr = chromium; Cu = copper; DDD = dichlorodiphenyldichloroethane, DDE = dichlorodiphenyldichloroethylene; Ni = nickel; Pb = lead; PCB = polychlorinated biphenyl; Zn = zinc.
Source: Carignan et al. (1994).

gases can be traced to automobiles, refineries, filling stations, and other sources related to the use of the automobile. Many of these sources are local (roads in the Windsor–Quebec City corridor are the most heavily travelled in the country), but the precursor gases are also transported to the region from heavily urbanized areas in the U.S. part of the Great Lakes basin and the American Midwest. For these reasons, the Windsor–Quebec City corridor has the highest concentrations of ground-level ozone in Canada (Fig. 6.21).

However, owing to a process of ozone "scavenging," ozone concentrations are often highest not in the big cities but in suburban and rural areas downwind from them (see Chapter 10). Thus, the highest concentrations have been observed in places like Long Point on Lake Erie and Tiverton and Grand Bend on Lake Huron. Along lakeshores, ozone or its precursors can become trapped in closed cells of air, tens of kilometres wide and up to 1 000 m high, that can prevent the dispersion of these pollutants for days.

Ground-level ozone concentrations depend on weather conditions and so tend to be highest during hot, dry summers, such as the summer of 1988. Weather conditions were generally less conducive to ozone formation in the early 1990s. However, because U.S. and Canadian emissions of nitrogen oxides and VOCs remain close to the levels of the mid-1980s (see Chapter 10), the potential for ozone pollution has not diminished. In fact, emission abatement requirements in Michigan, a significant source of nitrogen oxides and VOCs in the corridor, have recently been relaxed, and Ohio, another important source, is also considering relaxing its requirements. Thus, aside from variations caused by climate variability, ozone concentrations are expected to change little in the near future. Ground-level ozone is known to damage beans, tobacco, and other sensitive crops.

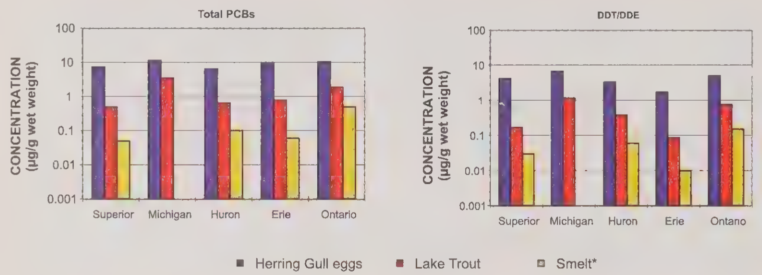
A second major air quality issue is that of suspended particulates, which are the result of automobile emissions and emissions from the numerous industrial plants in the corridor. The highest concentrations are thus found in places like Hamilton,

Toronto, Windsor, and Niagara Falls. Scrubbers and other control measures that have been installed in steel and other industrial plants have resulted in a slight downward trend in particulate levels over the last few years.

Of the other air pollutants commonly measured in the corridor, high sulphur dioxide concentrations have been observed near Sarnia (from the local petrochemical industry) and around Hamilton (from nearby metal processing plants). Nitrogen dioxide and carbon monoxide levels generally do not exceed air quality objectives.

The effects of air pollution on human health are briefly addressed in Chapter 10 and in the section on "The environment and human health" in this chapter.

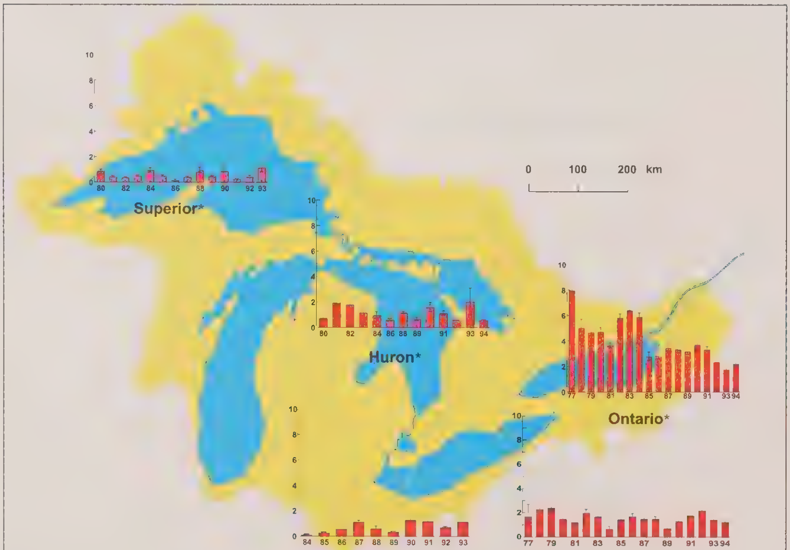
Figure 6.18
Concentrations of certain persistent toxic substances in biota from the Great Lakes, 1992



* Smelt data are not available for Lake Michigan.

Source: *Herring Gull data*: D.V. Weseloh, Canadian Wildlife Service, Environment Canada, personal communication; *Lake Trout data*: D.M. Whittle, Department of Fisheries and Oceans, personal communication, except Lake Michigan, for which data are from De Vault et al. (1996); *smelt data:* Department of Fisheries and Oceans, as reported in De Vault et al. (1995).

Figure 6.19
Trends in PCB concentrations in Lake Trout/Walleye in the Great Lakes, 1977–1994



* Data for Lake Trout.
** Data for Walleye.
Note: PCB concentrations are in µg/g wet weight ± S.E. (standard error), whole fish, age 4+.
Source: M. Whittle, Department of Fisheries and Oceans, personal communication.

Climate change

As discussed in Chapter 15, global temperature is expected to rise as a result of human-induced increases in greenhouse gases. State-of-the-art climate simulation models forecast an average global temperature increase of 1–3.5°C by the year 2100, corresponding to an increase of 0.1–0.3°C per decade (Intergovernmental Panel on Climate Change 1995). Such a change could be larger and faster than anything experienced during the last 10 000 years and could have dramatic effects on ecosystems and on human society. Between 1895 and 1993, an increase of 0.6°C in average annual temperature was actually observed in the Great Lakes–St. Lawrence basin (Mortsch 1995).

General circulation models and regional climate change scenarios

General circulation models (GCMs) can be used to simulate the difference between climates at different levels of carbon dioxide. Usually they simulate the difference between preindustrial levels of carbon dioxide (about 280 ppm in the late 1700s) and the doubling of that level (Hengeveld 1995). The various GCMs all agree reasonably well on average global temperature changes and large-scale regional climate features.

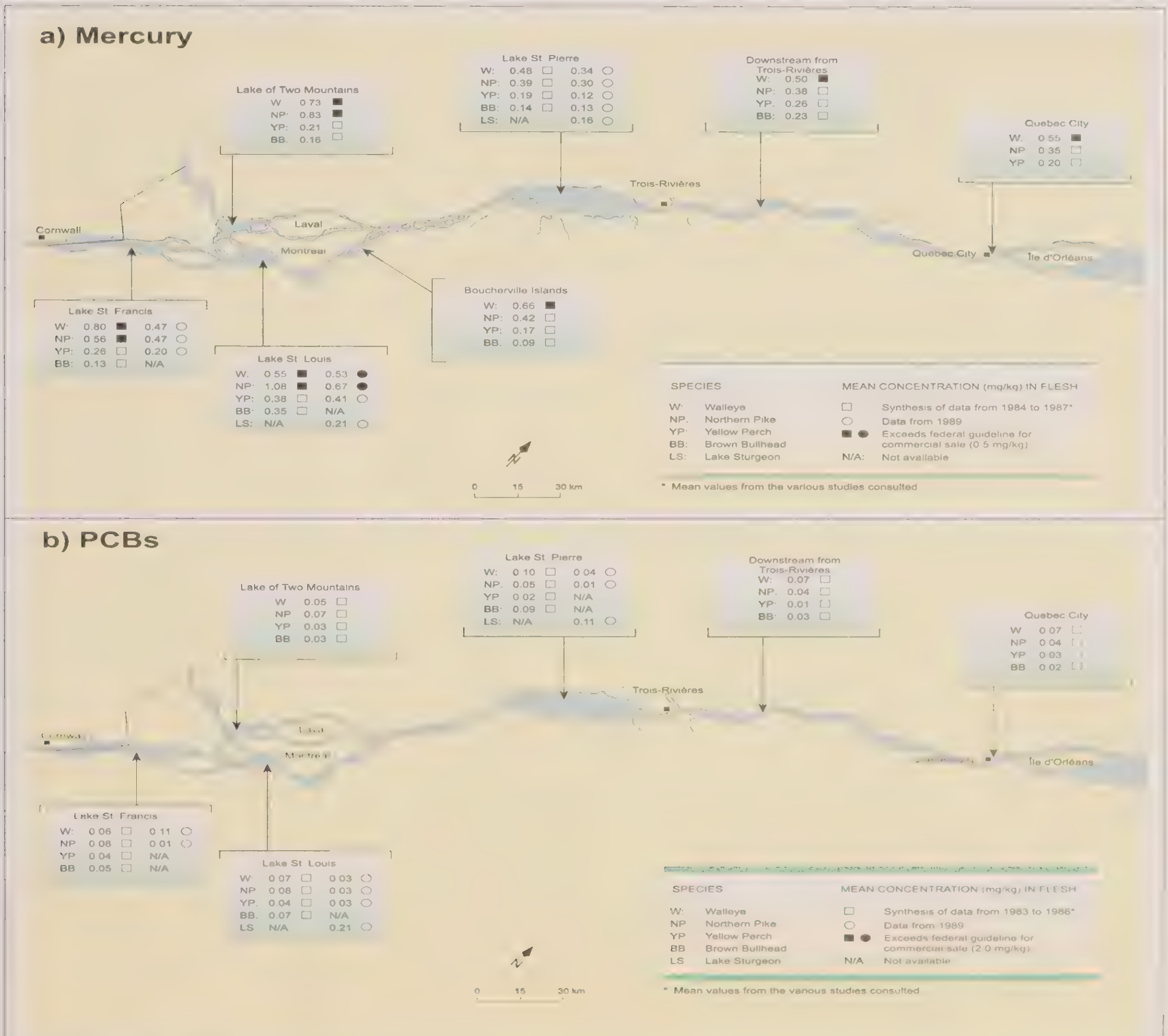
Differences in values produced by different GCMs may be as important as their similarities. Together, they describe a range of possible futures as well as the most likely directions of these futures. Mortsch and Burton (1992) compared the temperature and climate scenarios produced by different GCMs for the Great Lakes basin, based on a doubling of carbon dioxide relative to today's conditions. Most scenarios showed temperature increases of 3–9°C during one of the four seasons in some part of the basin. Most also showed the largest rise in temperature during winter and the small-

est during summer. The absolute values, however, differed by up to 5°C between scenarios; as well, some scenarios showed the highest increase in the south, whereas others showed it in the north of the basin. The range of precipitation shown in the different scenarios for different parts of the basin was even wider, ranging from a 10% increase to a 30% decrease in the south and from a 10% to a 40% increase in the north. They all agreed, however, in showing the highest increase in precipitation in the north of the basin.

GCMs have insufficient resolution to model small-scale regional characteristics, short-term variability, or extreme events such as severe storms and droughts. Yet weather events on these small scales have the most influence on the regional hydrologic cycle, regional ecosystems, and society. Pending development of more reliable regional atmospheric models, hydrologic models are used to explore different

Figure 6.20

Concentrations of mercury and PCBs in adult fish in different portions of the St. Lawrence River



Source: St. Lawrence Centre (1996a).

regional climate scenarios. These regional scenarios then become important inputs for developing "higher-order" impact scenarios for natural ecosystems, as well as for agriculture, navigation, urban development, and other activities.

Hydrologic models that have been developed and calibrated for the Great Lakes–St. Lawrence basin can only reflect the accuracy of the input data used, and results therefore differ considerably. As with the GCMs, a specific model result is best viewed as one scenario — one of a range of possible futures. Various hydrologic scenarios for the Great Lakes and St. Lawrence River differ in specifics, but they all paint a picture of significant changes within the next 100 years. Almost all show substantial decreases in water levels and outflows, and one even shows a total stop to the outflow from Lake Superior through the St. Marys River (Croley and Quinn 1996).

Potential effects

Scenarios for the potential impact of climate change present snapshots at some time in the future, not the end point of climate change. They do not consider the consequences of extreme weather events, which some models forecast may become more frequent. While many climate-related variables are involved, impact scenarios can consider only a few variables and must make the unrealistic assumption that other variables remain constant. They also do not take into account reactive adaptation, which is continually occurring in ecosystems and in human society. These simplifying assumptions make the scenarios more uncertain, especially as the complexity of scenarios increases and as impacts of impacts come into play. Following are some effects that the models have suggested for various categories of concern, summarized from Mortsch (1995).

Hydrology and water resources:

- decrease in groundwater recharge and increased moisture deficiency, leading to possible water shortages for those who rely on groundwater for their water supplies;
- reduced runoff to the Great Lakes by 8–25% and decreased outflow of the St. Lawrence by 20–40%;
- declines in lake levels, resulting in significant impacts on navigation and power generation;
- regionally reduced water supply and increased demand;
- increases in water temperature in the Great Lakes, with large decreases in the frequency of lake turnover and mixing;
- reduction or elimination of winter ice cover on all Great Lakes except Lake Erie; and
- significant shift upstream of the saltwater–freshwater boundary of the St. Lawrence.

Ecosystems:

- changes in distribution and location of wetlands and species, along with the risk that isolated wetlands or unique wildlife populations might disappear;
- changes in habitat that might favour successful colonization by exotic species;
- possible displacement of cold- and cool-water fish by warmer-water fish;
- 40–50% increase in frequency of forest fires in the Boreal Shield ecozone portion of the basin; and

Table 6.14

Principal contaminant-associated effects that have been observed in Great Lakes wildlife species from the 1960s to the present

Species	Population decline	Reproductive effects	Eggshell thinning	Congenital deformities	Behavioural changes	Biochemical changes	Increased mortality	Immune suppression
Mink	1990s	NE	NA	NE	NE	NE	NO	NE
Otter	1990s	NE	NA	NE	NE	NE	NO	NE
Double-crested Cormorant	1970s	1970s	1970s	1990s	NE	1990s	NO	NO
Black-crowned Night-Heron	1970s	1970s	1970s	1970s	NE	1980s	NO	NO
Bald Eagle	1990s	1990s	1990s	1990s	NE	NE	NE	NE
Herring Gull	1970s	1970s	1970s	1990s	1970s	1990s	1970s	1990s
Ring-billed Gull	NO	NE	NE	1970s	NE	NE	1970s	NE
Caspian Tern	1970s	1980s	NO	1970s	NE	1990s	NO	1990s
Common Tern	1970s	1990s	1970s	1980s	NE	1990s	NO	NE
Forster's Tern	NE	1990s	NE	1980s	1980s	1980s	NO	NE
Snapping Turtle	NE	1980s	NA	1980s	NE	NE	1980s	NE

NA = not applicable to this species
NE = species not examined for this effect
NO = no effect observed

Notes: 1. "19XXs" refers to the decade of the most recent observation reported in the published literature.
2. Increased mortality and/or alterations in recruitment are suspected where population declines have occurred.
3. Congenital deformities in Snapping Turtles were observed in field-collected eggs hatched in the laboratory.

Source: Government of Canada (1991a); Fox (1993): G.A. Fox, Canadian Wildlife Service, Environment Canada, personal communication.

- dieback of boreal forest along its southern boundaries and eventual replacement by hardwood forest.

Agriculture:

- if there is no successful adaptation, decreased productivity in the southern part of the basin, particularly the Lake Erie Lowland ecoregion, because of decreased soil moisture and increased frequency of drought; and
- extension northwards of areas where soybeans, fruit, corn, barley, and other high-value crops may be grown.

Human health:

- increased frequency of heat-influenced mortality;
- increased frequency of respiratory illnesses related to smog; and
- northward migration of malaria, Lyme disease, and other vector-borne diseases into the southern parts of the basin.

Scenarios have also been developed for transportation, energy production, tourism, and other sectors (Mortsch and Quinn 1995). These are highly uncertain, however, because of the ability of society to adapt to new conditions.

Environment Canada and several partners are currently conducting an integrated assessment of the potential impacts of climate change and variability on the Great Lakes–St. Lawrence basin. The project is examining the potential impacts of climate change for water management, land use, ecosystem health, and human health, as well as adaptive responses to recent climate extremes (e.g., the 1988 drought). A project at Case Western Reserve University in Cleveland, Ohio, aims to simulate the effects of different environmental, hydrological, socioeconomic, and institutional assumptions and to assist planners and the public in planning for climate change (Hobbs et al. 1993).

The environment and human health

Health perceptions

In 1993, Health and Welfare Canada conducted a survey on the perceptions of Canadians about health risks due to the environment (Health and Welfare Canada 1993). The results showed that a significant number of Canadians were concerned about the state of the environment and the effects it may have on their health. PCBs, dioxins, and other chemical pollutants ranked high on the list of concerns (Fig. 6.22). Manno et al. (1995) identified persistent organochlorines, metals, and microorganisms as being the environmental contaminants of most concern to human health in the Great Lakes–St. Lawrence basin.

Sources of exposure and body burdens

The main route of exposure to PCBs, dioxins, furans, organochlorine pesticides, and methylmercury is through food, particularly contaminated fish. Drinking untreated water is a principal route of exposure to microorganisms and a minor route of exposure to organochlorines and some metals. Breathing contaminated air is the obvious route of exposure to all types of airborne pollutants. Recreational use of water bodies leads to dermal exposure to waterborne chemicals and microbes (Manno et al. 1995).

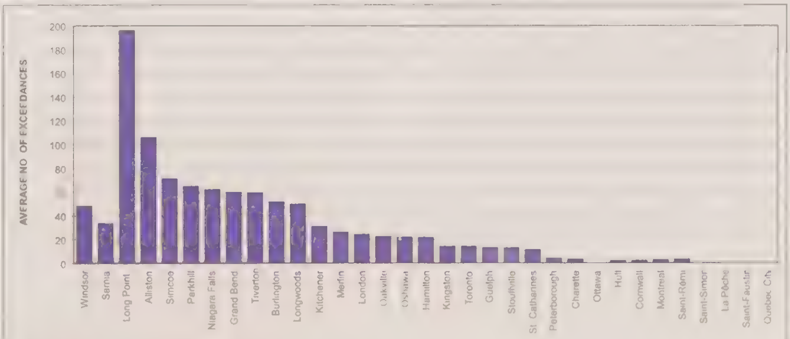
The few studies that have compared measurable body burdens of bioaccumulative, persistent toxic chemicals in residents of the Great Lakes–St. Lawrence basin have produced varying results. In general, people in the basin are exposed to levels of waterborne environmental contaminants similar to levels in other regions in Canada, the United States, and western Europe. However, because fish, Snapping Turtles, and some other "country foods" are highly contaminated in some areas of the basin, groups that consume large amounts of them are likely at risk of accumulating much larger body burdens than the general population. Groups thought to be at higher risk are anglers and their families, Aboriginal people, and certain other communities, such as recent immigrants from cultures with high fish consumption. Studies have been done to ascertain the body burdens of such groups, and more studies are in progress (see below).

Current body burdens are generally lower than those in the 1970s and 1980s, possibly due to reduced contaminant levels in fish and water or to decreased fish consumption, especially in high-risk populations. Women of child-bearing age in some Aboriginal communities have considerably reduced their fish consumption, and contaminant levels in their breast milk are as low as those in the general population.

In the 1960s, the concentration of DDT in the breast milk of Canadians was 10 times higher than it is today, and the samples from Ontario were approximately 25% higher than the national average

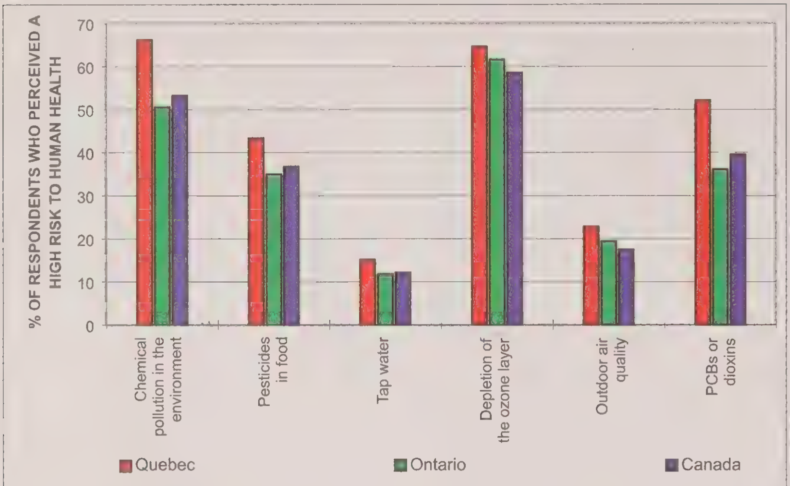
Figure 6.21

Number of exceedances of the acceptable concentration of ground-level ozone (82 ppb) along the Windsor–Quebec City corridor, 1994



Source Environmental Technology Centre, Environment Canada

Figure 6.22
Perceptions of health risks due to the environment: Quebec, Ontario, Canada



Source: Health and Welfare Canada (1993).

(Fig. 6.23). The levels of PCBs in Canadian breast milk reached their maximum in the early 1980s, when they were four times higher than today (Fig. 6.24). At that time, mean levels of PCBs in the samples from Quebec were about 35% higher than the national average. Today, levels of both DDT and PCBs in breast milk are about the same in Ontario and Quebec as in Canada as a whole (Mes 1994; Newsome et al. 1995).

People in the Windsor–Quebec City corridor are exposed to some of the highest levels of ground-level ozone, total suspended particles, and sulphates in Canada (Manno et al. 1995). With the possible exception of sulphates, these levels have not changed significantly since the mid-1980s (see Chapter 15 and the section on "Air pollution in the Windsor–Quebec City corridor: the price of the automobile?" in this chapter).

Health effects

Health effects due to the environment or to diet are suspected when there is a shift in the health of people in a specific area or in groups with specific behaviour patterns (e.g., fish consumption) or when people are exposed to high levels of contaminants or other agents that are known to cause harm at some level (e.g., persistent toxic chemicals or ultraviolet radiation).

These suspicions can be addressed by epidemiological or toxicological studies that determine:

- whether the health of these groups is significantly different from that of the rest of the population, and whether higher exposure to the suspected factor is linked to increased effects;
- whether the suspected factors are linked to the health of people under specific situations (e.g., workplace exposure, certain sources of drinking water);
- whether these factors cause harm or biochemical impacts in other species, in the wild or in controlled experiments; and
- whether the suspected effects are consistent with the current understanding of the workings of the human body and its biochemistry.

If the potential for harm is seen as very serious or irreversible, action may be taken even before the suspicions are confirmed or before the degree of harm linked to a specific level of exposure is determined. This form of decision-making has been labelled a weight-of-evidence approach (see the section on "Persistent toxic chemicals" in this chapter).

For persistent organochlorines (particularly PCBs), current information suggests that there are potential health effects for some groups of humans in the basin (Manno et al. 1995). Wildlife data indicate that reproductive and neurological effects can occur in the offspring of species with a high body burden of such chemicals and that interference with the immune system and hormone balance (particularly the sex hormone balance) may occur as a result of exposure (Fox 1992, 1993). Epidemiological data show subtle behavioural differences in the offspring of people consuming large amounts of Great Lakes fish (H.B. Daly, Center for Neurobehavioral Effects of Environmental Toxins and Department of Psychology, State University of New York, Oswego, New York, unpublished data). Other adverse effects reported for these children included lower birth weight, smaller head circumference, and increased susceptibility to infection (Manno et al. 1995 and references cited therein).

In southern Ontario, hospital admission rates for respiratory illnesses rose by 5–6% as air pollution increased from normal or background levels (e.g., see Burnett et al. 1994). Ozone and sulphates were the pollutants most strongly associated with the problem. Children under the age of two appeared to be the group most affected. For children in Hamilton and along the north shore of Lake Erie, lung function was observed to decrease 5–10% as air pollution increased (Manno et al. 1995 and references cited therein).

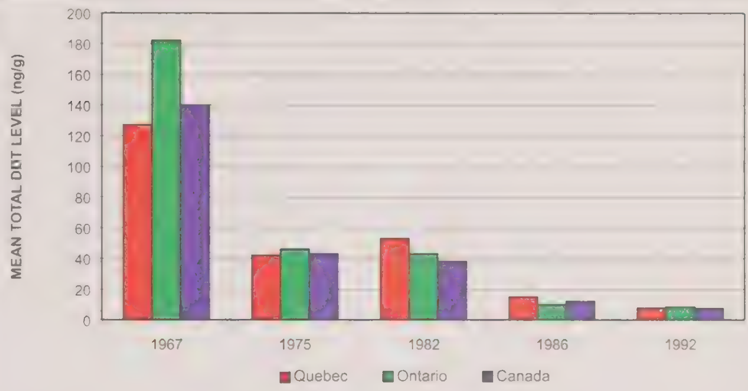
Effects from inorganic contaminants (e.g., mercury and lead) and radionuclides have not been observed for the basin and are thought to be no different from the effects on the population as a whole (Manno et al. 1995).

Improving our understanding

Work continues in the basin to study the levels of exposure of specific subpopulations to environmental contaminants and to determine whether there are health effects. The EAGLE (Effects on Aboriginals from the Great Lakes Environment) Project, a partnership between First Nations and Health Canada, is focusing on 63 Aboriginal communities in the Great Lakes basin (Assembly of First Nations 1993). Begun in 1990, the study is examining exposures of adults and children, concentrations of contaminants in blood, and the social and economic disturbances caused by these contaminants, particularly to the traditional way of life. The results of the project are expected to be available at the time of its completion in late 1997.

Figure 6.23

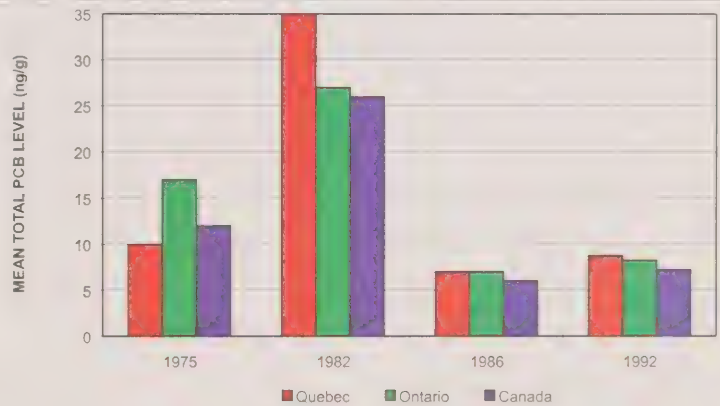
Trends in levels of DDT in human breast milk: Quebec, Ontario, Canada, 1967–1992



Source: Mes (1994); Newsome et al. (1995).

Figure 6.24

Trends in levels of PCBs in human breast milk: Quebec, Ontario, Canada, 1975–1992



Source: Mes (1994); Newsome et al. (1995).

SELECTED REGIONAL OVERVIEWS

Lake Superior basin

Lake Superior has the largest surface area of all lakes in the world, and only Lake Baikal in Russia surpasses it in depth and volume. Lake Superior contains 10% of all the surface fresh water in the world and has the largest drainage basin (210 000 km^2) of the Great Lakes (Fig. 6.25). The flushing time of water from the lake is 191 years.

Glaciation pushed most of the soil north of Lake Superior southward into what is now the United States, leaving behind chiefly morainal surface materials that have developed into shallow soils that are poor in nutrients. The basin includes thousands of lakes scattered throughout the predominantly boreal forests. The granitic bedrock of the Canadian Shield is dotted with valuable mineral deposits.

North and west of Thunder Bay, the climate of the Lake Superior basin resembles that of the eastern Prairies, with relatively cold winters and warm summers. Lake Superior itself tends to buffer seasonal air temperature changes. In summer, shoreline areas remain considerably cooler than points inland. Precipitation tends to increase in a southeastward progression across the basin, particularly in winter, when cold Arctic air masses regularly sweep across the basin, collecting moisture from the warmer lake surface and depositing it in the "snowbelts" on the southeastern shores of the lake.

Settlement and economy

Except for a few scattered fur-trading posts and silver mines, European colonization of the north shore of Lake Superior was slow. Railroad communities such as Schreiber and Thunder Bay blossomed when the railway was built in the late 1800s; today's forest product and mining-based communities are only about 50 years old. At the head of the lakes, Thunder Bay is the Canadian terminus of the St. Lawrence Seaway.

The Canadian side of the Lake Superior basin is home to approximately 182 000 people (Statistics Canada 1991), whereas there are about 426 000 living on the

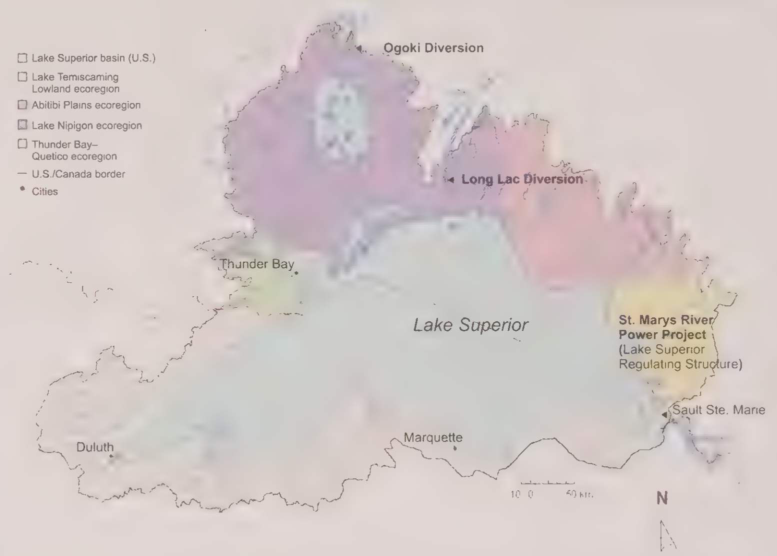
U.S. side (1990 census data, from Chapter 2, Table 1, in Allardice and Thorp 1995). As well as having fewer people, the north side of the lake is far less agricultural than the south side: almost 99% of the land in the Canadian portion of the basin remains forested, and 87% of that is provincially owned; in contrast, much of the shoreline and lands on the U.S. side are privately held.

The north shore's population centres are based on natural resource development. Pulp and paper mills operate in Thunder Bay, Red Rock, Terrace Bay, Marathon, and Sault Ste. Marie, and mines, although fewer in number now, still operate in Schreiber, Marathon, Manitouwadge, and Wawa. The south shore of the Lake Superior basin is responsible for three-quarters of U.S. iron ore production (Superior Work Group 1995).

Water transportation is still used to get goods out of the basin. The two largest ports are Thunder Bay, which handles mostly prairie grain, and Duluth, Minnesota, which ships iron ore, coal, and grain. However, in 1990, downstream cargo movement was only 40 million tonnes, compared with 89 million tonnes in 1970 (Environment Canada and U.S. Environmental Protection Agency 1995b).

The Superior basin has a classic hinterland economy: although the timber, pulp, and minerals produced in this area are destined for world markets, key decisions are made in corporate headquarters elsewhere, often outside Canada. Further, management decisions about a particular resource have often been made in relative isolation from decisions about other resources. This compartmentalization is slowly changing, however, as an ecosystem-based management approach gains wider acceptance. Today, many communities are encouraging tourism as a hedge against the cycles of the resource-based economy.

Figure 6.25
Lake Superior basin



Source: Prepared by the Water Issues Division, Environment Canada, Ontario Region, for the State of the Environment Directorate. Ecoregion boundaries from Ecological Stratification Working Group (1996).

Indicator species for biodiversity conservation

Biodiversity conservation involves the preservation of all aspects of the variety of life — the variety of species, the variety within species (genetic diversity), and the variety of ecosystems (see Chapter 14 and the "Biodiversity and habitat change" section of this chapter). The invasions of exotic species and the deliberate introductions of nonnative fish have altered the food web in and around Lake Superior (see the "Fisheries" section of this chapter). Habitat abundance and diversity have been influenced by the regulation of water levels at the St. Marys River outflow and the degradation of many productive embayments and river mouths. This degradation, associated with resource extraction industries and human settlement, has been affecting water and wetland quality since the late 1800s (Superior Work Group 1995).

Three key species in the basin are Peregrine Falcon, Woodland Caribou, and Lake Trout. The Lake Trout and Peregrine Falcon are top predators, depending upon the numbers and health of organisms at lower levels of their food webs. Both are good indicators of the presence and effects of toxic chemicals, which tend to get concentrated as they are passed upwards through a food web. Woodland Caribou inhabit the spruce–pine–fir forests that used to dominate the Lake Superior basin before modification of many of the forest ecosystems; the presence of Caribou is therefore a good indicator of the survival of the mature boreal forest in the basin.

Return of the Peregrine Falcon

Peregrine Falcons were extirpated from Ontario in the 1950s, their demise linked to the use of DDT and other persistent organochlorine pesticides (see Chapter 10 for a brief discussion of the relationship between DDT and the phenomenon of eggshell thinning). The ban on DDT use since 1970 and decreasing environmental levels of DDT and other organochlorines led biologists to try to rehabilitate the falcons. In 1973, the Canadian Wildlife Service launched the Peregrine Recovery Program, which raised young birds for release in the wild. It was not until the late 1980s, however, that any of the released birds were observed to reproduce. In 1989, the Thunder Bay Field Naturalists, with the support of the Federation of Ontario

Naturalists, World Wildlife Fund (Canada), Ontario Ministry of Natural Resources, and Environment Canada, launched Project Peregrine, an attempt to reintroduce the species to the Lake Superior shoreline cliff faces, which are among the best high-cliff habitat in the Great Lakes basin. To date, 60 birds have been released, and support for the program has broadened to other nongovernmental organizations, the corporate sector, the Lake Superior Binational Program (see below), and the Environmental Youth Corps. Adult birds bearing leg bands are now regularly observed. Monitoring since 1993 has shown that five breeding pairs on the north shore have successfully fledged young birds, and two other pairs have been sighted.

Woodland Caribou

Woodland Caribou populations once extended all along the north shore of Lake Superior and even into Minnesota and Michigan. Today, there are only a few remnant populations along the north shore; most populations are farther north, out of the way of roads and logging operations. The largest and most stable populations of Woodland Caribou are those in the Wabakimi Provincial Park and Lake Nipigon areas: a few hundred animals. Woodland Caribou have declined or disappeared because of habitat changes associated with logging, increased predation by Wolves, and their high sensitivity to disturbance by humans and their noisy machines. Three habitats are judged critical to the survival of Woodland Caribou:

- winter habitat, where the animals feed on lichens;
- calving areas (usually islands); and
- migration corridors, often 100 km or more in width.

A possible course of action to preserve or increase Woodland Caribou is to protect those populations that live inside parks. Parks that could increase protection are the recently expanded Wabakimi Park, a proposed Lake Nipigon Islands Caribou Reserve, and a proposed marine conservation area on the islands in Lake Superior.

Lake Trout — back from the brink

Before 1950, Lake Superior supported many stocks of Lake Trout that maintained their distinctiveness by spawning at specific shoals and at specific times of the year (Thibodeau and Kelso 1990). Many of these distinct stocks are now extirpated, or their abundance has been seriously depressed (see the "Fisheries" section of this chapter). The governments of Canada, the United States, Ontario, and the eight states bordering the Great Lakes have been engaged in efforts to restore and rehabilitate Lake Trout stocks throughout the Great Lakes since the late 1960s. Stocking of hatchery-reared fish, regulation of the commercial and sport fisheries to reduce the harvest, and a costly but necessary program to limit Sea Lamprey abundance are important components of this undertaking. Restoration has been most successful in Lake Superior, where native remnant stocks have continued to reproduce using ancestral spawning sites, where stocking has continued for the longest period, and where reproduction by hatchery-origin fish has been significant. The abundance of indigenous stocks approaches historic levels in some locales, especially in the southern portion of the lake.

Toxic substances in the aquatic environment

Of all the Great Lakes, Lake Superior is the most remote from the large metropolitan and manufacturing centres of the basin and the one least exposed to direct discharges of contaminants. Air over Lake Superior contains only 15–20% of the PCBs found in the air near Chicago or Detroit (De Vault et al. 1995), and the lake receives only one-fifth as much PCBs and one-tenth as much mercury from regional sources (effluents, runoff, and tributaries) as does Lake Ontario (see Table 6.10; Strachan and Eisenreich 1988). Because of the large surface area of the lake, the atmosphere, through precipitation, dustfall, and vapour deposition, is a major source of its contaminants. However, the atmosphere also removes a considerable amount of the more volatile contaminants, such as PCBs, DDT, and even mercury, by volatilization (Jeremiason et al. 1994; Hoff et al. 1996). Although data are crude and not all pathways quantified, it appears that Lake Superior's role may have changed from that of a net sink to that of a net exporter of PCBs (Table 6.15).

The Lake Superior Binational Program (see below) has identified 52 major point sources of persistent toxic chemicals to the surface waters of Lake Superior. Among these are 27 industrial facilities, comprising forest products manufacturers, mines and metal processors, electricity generating stations, a wood preserver, an oil refinery, and a food processing plant; and 16 municipal water treatment plants, serving 50% of the population (Superior Work Group 1995).

Toxaphene, a complex mixture of chlorinated camphenes, is of special concern in Lake Superior because it is the dominant contaminant in Lake Trout in this lake, and it is one of the chemicals responsible for the continuing consumption advisories for sport fish. Lake Trout in the upper three lakes (Superior, Michigan, and Huron) have the highest levels of toxaphene in their tissues, and those of Lake Superior are the most contaminated next to those of Lake Michigan (De Vault et al. 1995).

After the ban on DDT, toxaphene became the most heavily used insecticide in the 1960s and 1970s. It was first used mainly on cotton in the southern United States, then on other crops and for the control of scabies on cattle and rough fish control (Howdeshell and Hites 1996). Toxaphene has not been registered in Canada since 1983, and it was banned in the United States in 1986; it still finds restricted use in some other countries (Mexico, Argentina, Spain, and Norway) (Voldner and Li 1995). Until recently, the source of toxaphene in Lake Superior was thought to be primarily long-range atmospheric transport (Voldner and Schroeder 1989). However, the lack of toxaphene in the lower lakes and recent comparisons of toxaphene in sediment cores from different locations (D. Swackhamer, University of

Minnesota, as cited in De Vault et al. 1995) have thrown doubt on this assumption. Local sources or inadvertent generation in the region are now being considered as additional possible sources.

Levels of other contaminants in Lake Superior biota are usually lower than those in lakes Ontario or Michigan but in the same range as in the other lakes, depending somewhat on species and contaminant (see Fig. 6.18; De Vault et al. 1995). An example is dioxin (2,3,7,8-TCDD), levels of which are almost 20 times lower in Lake Trout and 4 times lower in Herring Gull eggs of Lake Superior than in those of Lake Ontario (De Vault et al. 1995). Aside from toxaphene, another exception is mercury levels, which are higher than (smelt) or as high as (Lake Trout) in any other lake. As for toxaphene, an important source of mercury to Lake Superior is thought to be atmospheric transport (see Table 6.10). Although levels of many contaminants in Lake Superior biota have declined since the mid-1970s (best seen in Herring Gull eggs; Fig. 6.26), little decline has been observed since the mid-1980s (De Vault et al. 1995). This parallels the situation in the other lakes (see "Persistent toxic chemicals" section).

Forests

Two major types of forest characterize the basin north of Lake Superior. Well known from the paintings of Tom Thomson and the Group of Seven are the Red Pine, Eastern White Pine, Sugar Maple, Red Maple, and Yellow Birch of the Great Lakes–St. Lawrence forest, found in a thin curving arc close to the shores of Lake Superior, mainly south of Wawa. Most of the rest of the basin is typified by boreal forest communities, with Black Spruce, White Spruce, and Tamarack dominating on cold, wet, acidic soils and Jack Pine on dry sites. White Birch, Balsam Poplar, and Trembling Aspen are found in both types of forest.

Table 6.15
Estimated PCB mass balances for Lake Superior, 1986 and 1992

Flow	PCB input/output (kg/year) 1986	1992
Input (excluding vapour deposition)		
Wet and dry deposition	157	85
Tributaries	140	140
Direct discharges	38	38
Output (excluding volatilization)		
Sediment burial	–110	–110
River outflow	–60	–13
Net mass balance excluding vapour	**165**	**140**
Vapour deposition	300	320
Volatilization	–2 200	–2 000
Net vapour balance	–1 900	–1 680
Total mass balance including vapour	**–1 735**	**–1 540**

Notes: Estimates for tributary loadings range from 27 to 140 kg/year (De Vault et al. 1995 and this table); wet deposition, dry deposition, and net vapour exchange are thought to have an uncertainty of ± 22, 100, and 88%, respectively (Hoff et al. 1996).

Source: *1986 estimates*: wet and dry deposition, vapour deposition, and volatilization from Hoff et al. (1996); for tributary flow, see 1992 values below; sediment burial and outflow from Jeremiason et al. (1994); direct discharges from Dolan et al. (1993). *1992 estimates*: wet, dry, and vapour deposition from Hoff et al. (1996); for tributary flow, values measured during the summer months of 1991 (Burniston and Strachan 1996) were extrapolated to the whole year and used for 1986 and 1992; 1992 outflow was taken as proportional to water concentration and adjusted accordingly relative to the 1986 value (Jeremiason et al. 1994); direct discharges and sediment burial were taken as identical to 1986, as new data were not available.

In the early 1900s, most of the Red Pines and Eastern White Pines were harvested and exported to foreign markets; only a few uncut stands of those big pines remain, and there has been little natural or artificial regeneration. Since the Second World War, White Spruce, Black Spruce, and Jack Pine have been harvested in large clearcuts to supply pulp and paper mills. In the 1990s, short supplies of these conifers and new technologies have encouraged the use of Trembling Aspen and Balsam Poplar in making pulp and paper in modified or new mills.

Protected areas

Public agencies and private organizations have established parks and other protected special places within the Lake Superior basin to capture the purity that it offers. The following presents a couple of examples — Pukaskwa National Park and Wabakimi Provincial Park.

Established in 1987, Pukaskwa National Park is a 187 800-ha wilderness area along the Lake Superior shore. The park is representative of the rugged boreal upland of Black Spruce–Jack Pine forest and mammals such as Black Bear, Wolf, and Moose, as well as a remnant herd of just over a dozen Woodland Caribou. The park's coastal hills are influenced by the marine climate of Lake Superior; as a result, Pukaskwa also contains temperate Great Lakes–St. Lawrence forest. Rare Arctic plants are reminders of the park's recent glacial history. Agreements to establish the park involved the Aboriginal people of the Robinson–Superior Treaty group, who share the stewardship tasks; targets for at least 50% employment of band members in the park have been achieved.

The boreal forest ecosystem of Pukaskwa has been altered by fire suppression. In unmanaged systems, the "burn-down" from fires allows natural regeneration and increased diversity of habitat and species. The park now has a severe Spruce Budworm infestation in its aging forests. Fire management plans for the park, to be worked out with the Ontario Ministry of Natural Resources, will determine how to manage prescribed burns (and the atten-

dant dangers) as a tool to reestablish the role of fire in the boreal ecosystem.

Around Pukaskwa National Park, partnerships have been formed to begin integrated decision-making for the "greater park ecosystem" from Wawa to Marathon. Discussions are under way to create a regional plan to ensure that adjacent activities such as timber harvesting and mining will not affect the park.

Anchoring the Lake Superior network of protected areas is Wabakimi Provincial Park, at the northwestern corner of the drainage basin. Consisting of 900 000 ha of wilderness, Wabakimi is large enough to be a self-regulating ecosystem. It includes room for wildfires, several hundred Woodland Caribou, and perhaps the most extensive system of protected canoe routes in the world. The Lake Superior basin also has a number of small parks, nature reserves, and other protected areas.

An assemblage of parks cannot on its own conserve biodiversity. Each park or other protected area is part of a much larger landscape mosaic. Ideally, this mosaic would be constructed of healthy communities (socially and economically) that use land and natural resources in an ecologically sustainable manner.

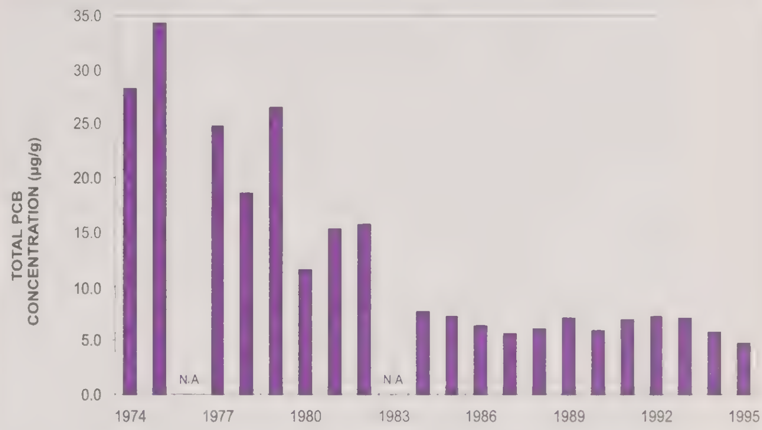
Sustainability

There are four designated Areas of Concern on the north shore of Lake Superior, each associated with a history of pollution in a harbour — Thunder Bay, Nipigon Bay, Jackfish Bay, and Peninsula Harbour (Fig. 6.13). A Remedial Action Plan with a public advisory committee is in place for each of these areas (Box 6.4). Pulp and paper mills and other forest products operations, although not the only source, are the main sources of the pollution in the four harbours (Hartig and Law 1994). Since 1990, the Clean-up Fund of Environment Canada has provided funding for sediment cleanup technology and habitat restoration.

In 1990, the IJC challenged the provincial, state, and federal governments of Canada and the United States to protect and restore the ecological integrity of Lake Superior by, among other initiatives,

Figure 6.26

Trends in total PCB concentrations in Herring Gull eggs in Lake Superior, 1974–1995



N/A = no data available

Note: PCB concentrations are averages of two Herring Gull colonies (Agawa Rock and Granite Island)

Source: Bishop et al. (1992b); Pettit et al. (1994b), D.V. Weseloh, Canadian Wildlife Service, Environment Canada, personal communication

making Lake Superior a demonstration project for the zero discharge of persistent toxic substances. Lake Superior was chosen because it is the largest and cleanest of the Great Lakes and because it is at the upper end of the drainage basin. The area has fewer people and industries than the other lakes, and thus programs undertaken here must deal with relatively less complex socioeconomic issues.

In response to the IJC challenge, the Lake Superior Binational Forum was created to initiate a broad-based dialogue on reducing toxic substances. The forum is a stakeholder group of citizen volunteers, industry representatives, environmental and Aboriginal organizations, academics, and municipalities interested in the Lake Superior ecosystem. Started by the Lake Superior Center in Duluth in 1990, the forum is exploring creative initiatives in pollution prevention, transition economics, and other ways to ultimately achieve the virtual elimination of persistent toxic substances. It provides regular feedback to the governments regarding the Binational Program (discussed below) and Lakewide Management Plans (see Box 6.4).

In 1991, the governments having jurisdiction in Lake Superior signed the Binational Program to Restore and Protect the Lake Superior Basin. They also formally adopted the Lake Superior Binational Forum as their main channel for feedback from stakeholders. The Binational Program is attempting to meet the goal of zero discharge for nine persistent, bioaccumulative, toxic compounds. Actions to be taken fall into three classes: pollution prevention, enhanced controls and regulations, and special designations for all or parts of the Lake Superior basin based on outstanding natural and heritage features. Grappling with zero discharge has been difficult. Although efforts to reduce or eliminate local sources of contaminants are continuing, much of the input is a result of long-range atmospheric transport from sources outside the jurisdictions of the participating agencies.

Those concerned with improving the way ecosystems are managed have needed to find an ecosystem to manage that is big enough to be dramatic and small enough to be manageable; big enough to be a model for ecosystem management on a global scale and small enough so that people can understand and relate to it. Such an exper-

Box 6.4
Overview of the Canadian Remedial Action Plan program

The 1987 revision of the Canada–United States Great Lakes Water Quality Agreement formalized the requirements for Remedial Action Plans (RAPs). Restoration of beneficial uses within the Areas of Concern (AOCs) is the primary mission of RAPs and is an essential step in restoring the integrity of the Great Lakes basin ecosystem.

Canada and Ontario committed themselves under the Canada–Ontario Agreement Respecting the Great Lakes Basin Ecosystem to joint development and implementation of RAPs for the Canadian AOCs. The lead provincial and federal agencies are the Ontario Ministry of Environment and Energy and Environment Canada, respectively. The current Canada–Ontario Agreement target is to restore 60% of all impaired uses, leading to the delisting of nine AOCs by the year 2000.

The Canada–Ontario Agreement RAP program emphasizes adoption of a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses and the area's ability to support aquatic life. Particular attention has been given to ensuring that the public is consulted on all aspects of the RAP program. Guidelines for public involvement were developed and implemented early in the program, and local public advisory committees were established to provide direction for the plans and to generate community awareness and support for them. This awareness and support are crucial for successful implementation of RAPs.

RAPs are an iterative, action-planning process used to identify the responsibility and time frame for implementing remedial and preventative actions necessary to restore impaired uses in a three-stage process. Stage 1 includes problem definition and identification of sources and causes of environmental degradation; Stage 2 identifies goals and remedial and preventative actions to restore beneficial uses; and Stage 3 requires confirmation of the effectiveness of those measures and restoration of the beneficial uses. Documents are developed at each of these stages and forwarded to the IJC for review and comment. To date, of the original 17 AOCs in Canada, one, Collingwood Harbour, has been delisted as an AOC (delisted in 1995; Hartig and Dolan 1995). The remaining 16 are at various stages of development and implementation.

One of the driving forces behind the Canadian RAPs is Environment Canada's Great Lakes Clean-up Fund. Since 1990, $43 million in federal funds has been directed to the goals of cleaning up contaminated harbour sediments using safe technologies, solving sewage treatment plant problems caused by combined storm and sanitary sewers, restoring and creating fish and wildlife habitat, and public education. This has levered an additional $79 million from other implementors.

Although the ultimate success of a RAP is measured by restoration of beneficial uses, including biological recovery, the critical content of RAPs consists of the clear identification of a limited number of key action steps that are essential to recovery. The process of identifying those high-priority actions and gaining support for their implementation lies at the heart of the RAP process. Many of the use impairments and problems in AOCs are similar; however, the site-specific approaches and solutions vary substantially. Therefore, it is important to continue to emphasize cooperative learning through RAPs, monitor progress, and recognize our mutual dependencies in restoring and maintaining the integrity of the Great Lakes.

Lakewide Management Plans (LaMPs) are intended to set lakewide reduction targets for critical pollutants. As such, they may seek reductions in pollutants that are not fully addressed by RAPs. RAPs contribute to lakewide resolution of impairments, as most industry and contaminated sediment are in AOCs. LaMPs will invariably reinforce the need for RAP implementation.

iment in ecosystem management has begun in the Lake Superior drainage basin.

Lake Erie basin

Most of the Lake Erie basin is characterized by a Carolinian ecosystem, a type of ecosystem that is predominant in the eastern United States. Its northern boundary in Ontario stretches from Windsor–Grand Bend in the west to the eastern border of Metropolitan Toronto. Generally flat and low, it features poorly drained, fertile soils of silt and clay, interspersed with occasional moraines and sand ridges. To the northeast, these plains rise up to meet the Niagara Escarpment. The shoreline, which extends along Lake Erie to western Lake Ontario, southern Lake Huron, and Lake St. Clair, consists of low-lying dunes, beach areas, and clay-till bluffs (Fig. 6.27).

The Canadian Carolinian zone represents a transition belt from the U.S. portion of the ecosystem in the south to the mixedwood region in the north, resulting in a unique combination of species and ecological conditions. The climate is influenced by the surrounding lakes, which function as heat sinks, and influxes of tropical air, particularly from the Gulf of Mexico. Indeed, the area has the warmest average temperatures in Ontario (Centre for Land and Water Stewardship 1994). The Carolinian zone contains more indigenous species than any other ecosystem in Canada.

Agroecosystems and urban settings

The mild climate and fertile soils create good conditions for agriculture and settlement. Consequently, the previously extensive forest cover has been reduced to small, isolated fragments. At present, agriculture represents 86% of the total land use mosaic; forest and urban uses account for 8% and 5%, respectively. Close to 100% of wetlands have been lost in some counties (Hagan 1994), while savannah and tall-grass prairie habitats have been reduced to less than 0.1% of their former range (Bakowsky and Riley 1994), and the quality of the forest and other remaining natural habitats has largely been degraded. Oldham (1990) documented that 40% of Ontario's rare plants are restricted to the Carolinian ecosystem, but 37 species have

no record of occurrence in the wild since 1964, and 101 others persist in five or fewer locations.

Although the Lake Erie Lowland ecoregion occupies only about 0.25% of Canada's land mass, it supports 25% of the country's population (Allen et al. 1990). It is the most urbanized and intensively farmed ecoregion of Canada. Overall, land use is dominated by intensive agriculture in the form of cash crop and vegetable production, and over 150 000 people are involved in agricultural production or processing. The industry is relatively profitable but has recently been criticized as environmentally destructive.

Pesticides are applied on over 3 million hectares in the Lake Erie Lowland ecoregion, most as herbicide (Statistics Canada 1994a). Organochlorines (e.g., DDT), although no longer used, persist in the environment for decades. Their impact on wildlife, especially top predators, has been well documented (Box 6.5). The newest pesticides (e.g., sulphonyl ureas) tend to exhibit higher efficiency, lower persistence, and reduced toxicity. Furthermore, integrated pest management strategies, which view pesticides as only one of a series of pest control measures, are being developed and implemented. In light of these developments, Food Systems 2002 has a goal of a 50% reduction in the total amount of pesticides used by the year 2002 (Ontario Ministry of Agriculture, Food and Rural Affairs 1994).

In the Lake Erie Lowland ecoregion, annual soil erosion can reach 100 t/ha on sloped fields and can result in decreases in crop yield of as much as 50% (Kachanoski et al. 1992). Off-farm effects include the sedimentation and turbidity of surrounding water bodies. This can increase the costs of supplying water and adversely affect aquatic vegetation (e.g., in the Rondeau Bay drainage basin north of Lake Erie), fish habitats, recreation, and navigation. Conservation tillage (the reduction and even elimination of cultivation) can be an effective form of erosion control. It may result in a ninefold decrease in sediment loss (Wall et al. 1994), while achieving comparable yields in light, sandy soils (Aspinall and Kachanoski 1993). Other erosion control practices implemented in the ecoregion include the use of winter cover crops, windbreaks, shelterbelts, and grassed waterways.

Figure 6.27
Lake Erie basin

Source: Prepared by the Water Issues Division, Environment Canada, Ontario Region, for the State of the Environment Directorate. Ecoregion boundaries from Ecological Stratification Working Group (1996).

Agriculture has a substantial impact on phosphorus and nitrogen loading in the Great Lakes. Since the mid-1980s, the relative importance of agriculture-related phosphorus loading, associated with sediment transport, has increased as a result of the success in controlling loading from point sources such as municipal waste (Sharpley et al. 1994). The main objective of the largely successful Soil and Water Environmental Enhancement Program (SWEEP), a joint program of the governments of Ontario and Canada, was to reduce phosphorus loading and maintain agricultural productivity through the implementation of conservation tillage. However, only 18% of farms in the ecoregion practise conservation tillage; accordingly, other methods are being proposed, including the reduction of inputs and the use of natural and artificial wetlands to function as water purification systems and nutrient sinks (Brix 1993).

Currently, the greatest change in land use is the conversion from agricultural to urban use. Most of the land affected is high-capability agricultural land, and the change in use is generally perceived as irreversible. It has been estimated that up to 70% of the Lake Erie Lowland ecoregion's agricultural base is now within 50 km of a major urban centre (B. McDonald, Agriculture and Agri-Food Canada, personal communication).

The sustainable management of the agroecosystem has involved changes in agricultural practices that have included significant reductions in pesticide application, nutrient loading, and soil erosion without compromising economic viabili-

ty. These changes reflect a growth in community awareness of the importance of conservation (S. Hilts, Land Resource Science, University of Guelph, personal communication).

Remnant natural habitats, restoration, and protected areas

Forest cover in the Lake Erie Lowland ecoregion ranges from 3% in Essex County to 16% in Haldimand–Norfolk County (Beazley and Nelson 1993). As clearing continued, the natural landscape became progressively more fragmented, resulting in remnant patches of reduced area and connectivity. At present, 84% of these forest remnants are less than 3 ha in area, and only 2% are over 100 ha (Pearce 1992). This fragmentation has been associated with invasion by exotic species, predation, disease, and nest parasitism. Surrounding land use continues to contribute substantially to the loss of both species and habitat.

Restoration is a process whereby indigenous biodiversity as well as ecosystem structure or function are returned to a desirable condition or to a preexisting state (Cairns 1993). Species-level efforts include reintroductions of the Southern Flying Squirrel at Point Pelee and the Wild Turkey in the Simcoe–Long Point area and research on the Cucumber Tree, a species of Magnolia (Allen et al. 1990). Habitat-level rehabilitation has been conducted on converted roads and cottage sites at Point Pelee, in Tree Plan Canada-sponsored afforestation projects throughout the ecoregion (van Hemessen 1994), as well as in wetland, savannah, and tall-grass prairie ecosystems at Pinery Provincial Park, Point Pelee, and Long Point. For protected and rehabilitated species and habitats to persist in the face of continued fragmentation and degradation, they must be incorporated into a larger network of natural areas that is managed at the ecosystem or regional level.

The most important examples of a natural Carolinian ecosystem that remain in the Lake Erie Lowland ecoregion, outside those of the First Nations, are in parks and conservation areas. However, these government-led land purchases cannot achieve the necessary degree of protection; consequently, trust agreements with private landowners have become of prime importance. Although development continues to threaten both natural habitats and farmland, at present there are no formal mechanisms for adequate protection of threatened land.

Box 6.5
The Bald Eagle

In the 1700s, the Bald Eagle ranged across much of the forested area of North America. Large populations nested along the Lake Erie shoreline, but population declines began to be noted in the 1950s, and by 1980 only three pairs were found nesting along Lake Erie's north shore; none reproduced successfully.

This decline was linked to the release of agricultural pesticides and industrial effluent, especially DDT and PCBs. Owing to the cumulative concentration of these substances at successively higher levels of the food web, long-lived predators such as the Bald Eagle became increasingly susceptible. However, restrictions on application throughout the 1970s resulted in lowered concentrations, and, by 1982, a meaningful reintroduction program was feasible.

The Lake of the Woods area of northwestern Ontario remains home to a large natural population of Bald Eagles. From 1983 to 1987, 28 eaglets were transferred from this population to Long Point in Lake Erie and along the Grand River northeast of Long Point. The flightless eaglets were raised in nesting towers, released when judged capable of sustained flight, and then closely monitored.

The reintroduction program has likely contributed to the increasing numbers of Bald Eagles now nesting in the region. However, residues of organochlorines such as PCBs continue to contribute to nest failure, decreased productivity after 3–5 years, and incidents of bill deformity. It is becoming clear that to be successful, reintroduction projects will have to be supplemented by broad-scale management efforts.

Source: McKeane and Weseloh (1993); Hunter (1994).

Long Point Biosphere Reserve and the surrounding region

The Long Point region contains the largest area of wetlands and woodlands remaining along the north shores of Lake Erie. The shoreline is characterized by high, eroding clay bluffs to the west, a 40-km-long sand spit with its associated dune and wetland systems, and low-lying beaches, wetlands, and bluffs to the east. The dune and wetland systems have an exceptionally rich mix of habitats, consisting of the open lake, shallow bays, sand bars, beaches, dunes, forests and scrub, ponds, and marshes. Some 20 distinct biotic communities have been described on Long Point (Heffernan and Nelson 1979), some 273 different species of birds have been banded, and about 700 species of vascular plants have been recorded (90 of them rare in Ontario, and 4 occurring nowhere else in Canada; Canadian MAB Committee 1990). The marshlands are important staging grounds for migrating waterfowl and small migrating birds and act as important spawning and nursery areas for fish.

In 1986, Long Point was officially designated as one of six biosphere reserves in Canada by UNESCO's Man and the Biosphere Programme (Canadian MAB Committee 1990). The reserve consists of a core protected area (Long Point National Wildlife Area), an offshore and an onshore buffer zone, including the Big Creek National Wildlife Area, and an undefined "zone of cooperation" extending inland, including the Backus woods and other Carolinian forest tracts. The larger region is primarily agricultural land and includes three small towns. One of these, Nanticoke, is the site of a steel mill, a thermal power plant, and an oil refinery. The point itself has an extensive cottage community.

The Man and the Biosphere Programme promotes conservation and resource use at

local and regional levels, and it fosters research, monitoring, and educational activities. Since its inception, the Long Point World Biosphere Reserve Foundation has created signs, brochures, and displays and has developed partnerships with research groups. Most recently, with the support of Environment Canada, a Long Point Country community action plan, prepared as a starting point towards responsible stewardship of resources at the drainage basin level (Robinson 1994), and two Smithsonian Institution biodiversity monitoring sites have been established. Programs are also under way to reintroduce the Bald Eagle and Wild Turkey and to restore tall-grass prairie.

Point Pelee National Park

The Point Pelee sandspit, extending several kilometres into Lake Erie, is the southernmost tip of Canada's mainland. It is 1 500 ha in area — one-third upland, consisting of forest, shrub thickets, Red Cedar savannah, and dune communities, and two-thirds wetland, in turn consisting of marsh and wet forest. Over 670 vascular plant species have been identified, of which 70 are provincially rare. Currently, 40% of the plant species are nonnative (Natural Resources Conservation 1980). Like Long Point marsh, the marsh at Point Pelee is of continental significance as a staging area for migratory birds; over 350 bird species have been recorded. Land use in the park is dominated by natural habitat, and only 10% of the park is allocated for recreational and infrastructure use. In contrast, land use in the surrounding landscape is primarily agricultural and urban, and only 3% of the total land cover remains natural habitat.

Point Pelee has been subjected to a long history of human-mediated disturbance. In the 1960s, a major "naturalizing" initiative was undertaken. All agriculture was terminated, many roads were removed, and cottages were purchased and torn down. There is now a multiscale ecosystem management plan that incorporates the principles of conservation biology, landscape ecology, and restoration science (Reive et al. 1992). The plan coordinates many management activities, including changes in shore management, the control of White-tailed Deer populations, the removal of problematic exotic species, the reintroduction of the Southern Flying Squirrel, and the building of Bald Eagle nesting platforms. Monitoring activities ranging from rare plants to sport fishing to visitor impacts have also been implemented. Sites of former intensive use have been allowed to regenerate over the past decade, and, on a larger scale, the degraded Red Cedar savannah is being restored.

There is now recognition that many of the park's problems are transboundary in nature (Stephenson 1995) and that park management has to be coordinated at a landscape level if the ecological integrity of Point Pelee is to be maintained (Reive et al. 1992). Parks Canada is an active member of the multiagency Natural Habitat Restoration Program, which coordinates the local collection of seed and the planting of marginal farmland with native tree seedlings (Natural Habitat Restoration Program 1993). Satellite imagery of the area surrounding the park is being used to identify priority sites for similar restoration and conservation efforts (McLachlan and Bazely 1995).

Walpole Island

Traditionally called Bkejwanong (where the waters divide), Walpole Island is located on the large delta at the mouth of the St. Clair River. It is 24 000 ha in area, two-thirds dryland and one-third comprising marshes, sloughs, and interior lakes (M. Williams, Natural Heritage Centre, Walpole Island First Nation, personal communication; Woodliffe and Allen 1990).

Inhabiting the delta are 2 100 Ojibwa, Potawatomi, and Ottawa, comprising the Three Fires Confederacy. People engage in seasonal, resource-based activities, mainly hunting, fishing, and trapping (Jacobs 1994). Agriculture is primarily corn and soybean production. Most of the agricultural land is leased to neighbouring farmers, but as leases expire they are being purchased by an Aboriginal-run cooperative (Jackson 1993).

Walpole Island contains extensive mature woodland as well as the most important savannah (Box 6.6) and tall-grass prairie remaining in Canada (Woodliffe and Williams 1992). It is also a key staging area for migratory waterfowl and serves as an important fish spawning and nursery area (Jacobs and Williams 1989). More than 800 species of vascular plants, 96 of which are provincially rare, and 44 rare animal species occur on the island. This is the largest number for any single natural area in the province (Woodliffe and Allen 1990). This rich natural heritage is a direct reflection of the relationship between the residents and their environment. Because of their physical, cultural, spiritual, and economic ties to the land, the residents have successfully managed the site's resources (Jacobs 1994). Traditional knowledge of local natural cycles and processes as well as customary practice provide the basis for local resource management.

A growing population, high unemployment, and agriculture are putting pressure on the remaining upland habitat, resulting in substantial land use changes. For example, between 1963 and 1978, 4.5% of the wetlands were diked and converted to agricultural use. Consequently, the identification and protection of high-quality savannah and prairie have become a primary concern (Nin.Da.Waab.Jig 1990).

Upstream, the "chemical valley" south of Sarnia discharges 2 million cubic metres of effluent into the river each day (St. Clair River Remedial Action Plan 1991). Between 1974 and 1986, 32 large spills of 10 t or more released pollutants into the river, and 100 smaller spills still occur each year (Jackson 1993). High levels of heavy metals deposited prior to 1970 remain in sediments and in resident duck populations (Jacobs 1994).

The commercial fishery on Lake St. Clair was closed in 1970 because of high mercury levels in fish, and it remains closed today, except for one licence (one family on Walpole Island since 1980). Consumption advisories for several fish species are still in effect. The Walpole Island community, however, depends heavily on fish as a major food source; exposure levels and the effects of contaminants on residents are unknown (M. Williams, Natural Heritage

Centre, Walpole Island First Nation, personal communication).

Aquatic communities

Lake Erie is highly susceptible to environmental disturbance because of its shallowness, short water replacement time (2.6 years), and location (90% of its inflow comes from the Detroit River). Changes in the lake's biological productivity and the structure of its aquatic food web are rapid and involve most of the lake.

Lake Erie is divided into three basins of increasing depth from west to east. Each lake basin has a different trophic status (i.e., nutrient content; see section on "Eutrophication of water bodies") and different aquatic communities. The shallower, warmer waters of the western basin are well mixed, relatively fertile, and well protected by islands. In contrast, the deeper, colder waters of the central and eastern basins are more open, less well mixed, and less productive biologically. At the height of commercial fishing in the 1950s, Lake Erie annually yielded over 40 000 t of commercial catch; more recently, the lake yielded approximately 42 000 t in 1990, split evenly between commercial and sport fisheries (U.S. Department of the Interior 1995).

Historically, the offshore fish community in the deep waters of the eastern and central basins of Lake Erie was dominated by the plankton-eating Lake Herring, the benthic macroinvertebrate-consuming Lake Whitefish, and the Blue Pike (a species endemic to lakes Erie and Ontario but which is now extinct), which fed on other fish. Lake Trout were found mainly in the deep eastern basin. Predation by Sea Lamprey on Lake Trout and Lake Whitefish, overfishing by the commercial fishery, and habitat destruction led to the demise of all these species by the late 1950s. Furthermore, massive inputs of phosphorus and other nutrients increased the fertility of the waters throughout the lake, resulting in an explosion of algal growth in the offshore waters. Decomposing algae in the deep offshore waters during the summer led to frequent episodes of anoxia and contributed to the decline of the offshore species. The ecological gap left by the disappearance of the Lake Herring was filled by the nonindigenous Rainbow Smelt (see the "Fisheries" section of this chapter), which by 1990 had become the most important offshore component of Lake Erie's commercial harvest (U.S. Department of the Interior 1995). Walleye and, in the eastern basin, stocked salmonids (Brown Trout, Rainbow Trout, Coho Salmon, and Chinook Salmon) are now the top predators in the aquatic food web.

In the nearshore areas, overfishing, damming of rivers, increased siltation, and destruction of wetlands led to the demise of Lake Sturgeon by the early 1900s and of most of the top piscivores (Northern Pike, Sauger, and Muskellunge) by the 1950s. Yellow Perch and Walleye are currently the primary species sought by the commercial fishery, but there is concern that existing stocks may not be able to sustain these harvesting pressures as the system responds to reductions in nutrient loadings (U.S. Department of the Interior 1995). Yellow Perch abundance has been declining since 1990.

By the 1960s, numerous reports were proclaiming that Lake Erie was dead or dying. The problem was traced to the huge increases in nutrient inputs, particularly phosphorus, from sewage and agricultural runoff that accompanied rapid urban expansion and increased fertilizer use after the Second World War. The implementation of the 1972 Great Lakes Water Quality Agreement (see Box 6.3) began to reverse the eutrophication. Initial efforts focused on controlling nutrient inputs from point sources, such as pipe outlets at sewage treatment plants. These controls reduced annual loadings from a peak of over 19 000 t in 1978 to 8 000–13 000 t between 1987 and 1992. About 50–70% of the phosphorus input to the lake now comes from nonpoint sources, particularly agriculture, which are much more difficult and costly to control. After correcting for atmospheric inputs, annual loads have fluctuated

Box 6.6
Savannah

Oak savannah and tall-grass prairie are two of the most threatened vegetation types in North America. In Canada, oak savannah is indigenous only to the very southern part of Ontario (southern Lake Erie Lowland ecoregion). In the 1700s, these vegetation types covered 2.4% of southern Ontario; today, they amount to less than 0.1%. The disappearance of these ecosystems was at first the result of their suitability for agriculture and of the deliberate suppression of grass fires. Later, residential and commercial development and invasion by exotic species became contributing factors. Destruction and degradation of these habitats led to the decline of species associated with them (e.g., Frosted Elfin and Karner Blue butterflies, and others).

Walpole Island now contains the most significant tall-grass prairie and oak savannah in Canada, maintained by communal efforts (including deliberate, large-scale burning) of the Walpole Island First Nation. The preservation of this valuable habitat attests to the strengths of traditional knowledge and environmental stewardship still practised by this First Nation.

Other areas of prairie and oak savannah habitat are found at Pinery Provincial Park on Lake Huron and Ojibwa Park in Windsor. Elsewhere in southern Ontario, the degradation of the few remaining sites is such that rehabilitation is necessary. Seeds are being collected, research is being carried out, and projects to rehabilitate prairie and savannah habitat have begun on Long Point and Pinery provincial parks, in Point Pelee National Park, on private land, and, somewhat controversially, in High Park in Toronto.

Source: Jacobs and Williams (1989); Packer (1990); Woodliffe and Allen (1990); Bakowsky and Riley (1994).

between 3 700 t (in 1992) and 8 200 t (in 1990), depending on annual precipitation (D. Dolan, IJC, personal communication).

The reduced nutrient loadings have lowered biological productivity in all three basins. Furthermore, the frequency of anoxic events in the central basin has decreased (see section on "Eutrophication of water bodies"), and fish kills due to anoxia are rare. The lower fertility of the waters of Lake Erie also seems to be one of the likely causes of the decrease and redistribution (from the eastern to the central basin) of Rainbow Smelt and other forage fish and, together with the invasion of Zebra and Quagga mussels, of a shift from open-water to bottom-feeding communities. These less productive conditions may also favour a return of Lake Herring, Lake Whitefish, and other indigenous species. Fisheries agencies have reduced the number of trout and salmon stocked in Lake Erie from a peak of almost 3.5 million yearlings in 1989 to about 2.2 million in 1995, most of them Rainbow Trout (J. Fitzsimons, Department of Fisheries and Oceans, personal communication). Lake Trout recovery plans have been implemented, and consideration is being given to initiating efforts to restore Lake Sturgeon.

The Lake Erie ecosystem may be undergoing extensive changes as a result of the colonization of the lake by Zebra and Quagga mussels since 1989 (Leach 1993). The Quagga Mussel is common on sediments at depths exceeding 40 m, whereas the Zebra Mussel is more abundant in the shallower, warmer waters of the lake (Dermott and Munawar 1993). By 1992, at least 80% of Lake Erie's bottom sediments had been invaded (Dermott and Munawar 1993), and densities as high as 350 000 mussels/m^2 were reported on reefs in the western basin (Leach 1993). Zebra and Quagga mussels are now the dominant (over 90% of biomass) benthic organisms in Lake Erie (U.S. Department of the Interior 1995; R. Dermott, Canada Centre for Inland Waters, Department of Fisheries and Oceans, personal communication).

The invasion of Lake Erie by Zebra and Quagga mussels has clearly resulted in a shift in food web dynamics (and the flow of energy) from the open-water food web (Rainbow Smelt, Lake Herring, Pacific salmon) to the benthic food web (Dermott and Munawar 1993; U.S. Department of the Interior 1995). Within five years of their invasion, dramatic increases in water clarity (Leach 1993), declines in phytoplankton abundance (Leach 1993; Holland et al. 1995), and changes in the benthic macroinvertebrate community (Schloesser and Nalepa 1994) were reported. The increased water clarity means that rooted aquatic plants are able to grow at greater depths than before and that prey species are more visible to their predators. A rapid and widespread decline in the abundance of indigenous freshwater mussels (from 53% of live mussels sampled in September 1989 to 0% a year later) was attributed to Zebra Mussels (Schloesser and Nalepa 1994). Competition for space and food has also resulted in declines in the abundance of the native burrowing amphipod (*Diporeia hoyi*) in deep waters (Dermott and Munawar 1993). However, contrary to initial concerns, the dense colonization of spawning reefs has not adversely affected Walleye reproduction or abundance at open-lake shoals (Fitzsimons et al. 1995). In 1990, Zebra Mussels filtered an estimated 4.0–8.8 million tonnes of phytoplankton, or between 16 and 36% of the total primary production, from the water column in the western basin (Madenjian 1995). Of this total, roughly four-fifths was consumed, and the rest was deposited on the bottom, providing a rich substrate for bacteria and other benthic organisms. The phytoplankton consumed by Zebra and Quagga mussels are also food for larger zooplankton, which, in turn, are consumed by Alewife, Rainbow Smelt, Lake Herring, and other fish.

The indirect effects of the mussels on these fish species are not yet known. Fish predation of Zebra and Quagga mussels is thought to be negligible relative to the ability of the mussels to reproduce and disperse (U.S. Department of the Interior 1995). The general strengthening of benthic food webs caused by the invasion of Zebra and Quagga mussels may favour macroinvertebrate-feeding species such as Lake Whitefish and top predators such as Walleye and Lake Trout. Water quality improvements resulting from the implementation of Remedial Action Plans in Areas of Concern such as the Cuyahoga River in Cleveland may mean that river spawning sites will again become available and that the trend towards stronger benthic and nearshore communities will be reinforced. However, colonization by other exotic species such as the Ruffe and Round Goby may introduce further uncertainties.

Lake Ontario basin

A dominant feature of the Lake Ontario basin (Fig. 6.28) — the lowest lake in the Great Lakes chain — is the large urban cluster at the western end of the lake, an area that is often referred to as the Golden Horseshoe. This region, centred on the Greater Toronto Area and Hamilton, extends from Oshawa through the Niagara Peninsula to Buffalo, New York. The Golden Horseshoe is at the heart of an extensive system of transportation corridors and has been the principal centre of population concentration and economic development in southern Ontario for two centuries. Approximately 90% of the Canadian population of the Lake Ontario basin lives in urban areas; the Greater Toronto Area (4.2 million people) and Hamilton (0.6 million people) account for 98% of this urban population (Statistics Canada 1994b).

The landscape surrounding the urban areas consists of a mosaic of fields in cultivation — including the highly productive Niagara fruit belt — and small woodlots. Most of the woodlots are found in the hilly terrain of the Oak Ridges Moraine to the north and the Niagara Escarpment to the west, which are both under increasing development pressure from urban sprawl. The coarse sandy and gravelly soils of the Oak Ridges Moraine and Niagara Escarpment are porous and provide groundwater to the headwaters of streams draining into Lake Ontario. These landforms support some of the last areas of remnant natural vegetation in southern Ontario, and their plant and animal communities include species relatively intolerant of degraded conditions arising from human activities. As well, the Lake Ontario ecosystem possesses natural coastal wetlands in sheltered embayments

and stream mouths and nearshore shoals and reefs that fish such as Lake Trout use for spawning and feeding. Because these areas are so productive and support such biodiversity, their protection from further degradation is essential.

The Lake Ontario basin has long been dominated by the built network of urban centres and transportation corridors and by activities such as deforestation, damming of streams, overfishing and overhunting, disposal of toxic chemicals and other human wastes, encroachments on wetlands, and introductions of exotic species. These activities have altered ecological processes, degraded biological communities, and reduced the quality of human amenities within the basin. More than twice as many Canadians as Americans live in the basin; therefore, much of the onus for environmental reform is on Canadians.

Greater Toronto Area

The Greater Toronto Area is one of the fastest-growing regions in Canada (Fig. 6.29), with a net population gain of about 100 000 people per year (Allardice and Thorp 1995). Although the forces that determine this population growth cannot necessarily be controlled locally, local efforts can largely control the form that the growth takes. Currently, that growth is occurring in low-density housing in the suburbs and communities adjacent to Metropolitan Toronto and is encroaching on agricultural lands, wetlands, woodlots, and lakefront areas (IBI Group 1990). The low population density of the suburbs makes mitigation of the negative impacts more difficult, as a larger area is affected (see Chapter 12).

Several factors facilitate urban sprawl, among them the construction of new roads and the expansion of existing highways to attract industry. Better transportation corridors, in turn, encourage commuting over increasing distances from the core areas. Air pollution and crowding in the downtown core discourage people from living there; as more people move to the suburbs and commute to work, the air pollution gets worse. Other models of growth, such as infilling of existing urban areas or nodal growth in satellite communities, are possible and may mitigate some of the negative effects of urban sprawl, such as the "brownfield sites" (vacant, untended lots) that tend to surround large urban areas.

The ecological health of the streams, river mouth marshes and embayments, and shoreline areas in the Greater Toronto Area, which can be judged by the fish communities they support, is strongly influenced by land use in the surrounding areas (Wichert 1994). Some of the small headwater streams draining the Oak Ridges Moraine and Niagara Escarpment, particularly in the upper reaches of the Credit River and Duffins Creek drainage basins, still resemble their pristine states and support Brook Trout and Mottled Sculpin (Steedman 1988). In southern Ontario, the presence of Brook Trout is an indicator of relatively healthy stream ecosystems; this species is sensitive to the degrading effects of conventional urban and agricultural practices. Farther downstream, removal of the vegetation and the increasing imperviousness of the land surface have led to reductions in summer water flows and warming of the waters. At the same time, large quantities of suspended sediments and nutrients from agricultural fertilizers and human and animal wastes have been carried into the waters by surface runoff.

Losses of biodiversity have been greatest in the lower reaches of streams near Lake Ontario and along the waterfront itself, where urbanization has been most intensive and the cumulative effects of upstream activities have become most apparent. However, the main reaches of the larger streams where they flow through the old urban areas of Metropolitan Toronto are now less degraded than they were 40 or 50 years ago (Wichert 1994) and support some minnows and small sunfishes. This improvement, particularly in the Humber and Don rivers, stems from the decommissioning of sewage treatment plants on these streams and the redirecting of sewage to four large facilities discharging at or near Lake Ontario (Wichert 1994). In contrast, the ecological health of areas in which urbanization has occurred since the late 1940s, especially north of Metropolitan Toronto, has deteriorated,

Figure 6.28
Lake Ontario basin

Source: Prepared by the Water Issues Division, Environment Canada, Ontario Region, for the State of the Environment Directorate. Ecoregion boundaries from Ecological Stratification Working Group (1996).

because they are receiving greater volumes of surface runoff, larger quantities of suspended sediments from construction sites, and pollutants from streets and industrial plants (Steedman 1988; Wichert 1994). The cumulative effects of this diffuse runoff from recently urbanized areas in the mid-reaches may offset improvements in the lower reaches near Lake Ontario (Wichert 1994).

Within the boundaries of Metropolitan Toronto, the Rouge River and its valley were made into the largest natural urban park in Canada in 1990. Originally covering 4 250 ha, the Rouge Park has been expanded to 4 650 ha through the addition of some of the tablelands above the valley on the eastern side of the drainage basin. The park was created through the cooperation of all levels of government and the public. It contains a significant remnant of Carolinian forest and is home to species not normally found in highly urbanized areas, including White-tailed Deer, Red Fox, 38 regionally rare species of birds (e.g., Osprey and Pileated Woodpecker), and two nationally vulnerable species of fish (Central Stoneroller and Redside Dace). The park also includes regionally important wetlands and environmentally sensitive areas.

Based on a history of severe environmental degradation, the Metropolitan Toronto waterfront has been identified as an Area of Concern by the IJC. A Remedial Action Plan process (see Box 6.4) is under way to restore the polluted watercourses from Etobicoke Creek to the Rouge River and the waterfront itself (Metro Toronto and Region Remedial Action Plan 1994). Twelve specific goals have been set for improving water quality and restoring habitat. Water quality and habitat are degraded by contamination from stormwater runoff, combined sewer overflows after heavy rainfalls, and sewage treatment plants. Implementation of the Toronto Remedial Action Plan will be a long-term process. The funding of infrastructure for sewage treatment and stormwater control is a central issue that will require cooperative efforts from all levels of government; preliminary estimates set the cost at $2 billion over 25 years. The city's construction of two large water detention tanks to capture stormwater overflow reduced the number of beach closures in 1995.

Figure 6.29
Greater Toronto Area

Source: Prepared by the Water Issues Division, Environment Canada, Ontario Region, for the State of the Environment Directorate.

Lake Ontario fisheries

Historically, Lake Ontario's fish community was dominated by bottom-dwelling species, including large fish such as Lake Trout, Lake Whitefish, Burbot, and Lake Sturgeon and smaller fish such as sculpins, ciscoes, and Lake Herring (see the "Fisheries" section earlier in this chapter). Through a combination of habitat destruction, overfishing, and species introductions, the benthic community became degraded through the mid-1900s. The fish community rapidly became dominated by fish species resident in the pelagic zone. Commercial catches of Lake Trout, Lake Whitefish, ciscoes, and Lake Herring went from relatively stable, high yields that had been maintained for decades to positions of commercial extinction. Lake Trout and ciscoes were eventually extirpated.

The pelagic community has remained dominant since the mid-1950s, in part because of the proliferation of Rainbow Smelt and Alewife and the stocking of massive numbers of Coho and Chinook salmon (Kerr and LeTendre 1991). Salmon stocking (Fig. 6.30) was necessitated by the inherent instability of the system, as illustrated by periodic and massive die-offs of Alewife in the 1960s and early 1970s.

Restoration of Lake Ontario's benthic fish community began in the 1970s with efforts to reverse eutrophication (see section on "Eutrophication of water bodies"), along with Sea Lamprey controls and stocking of Lake Trout. Modest increases in Lake Whitefish and Burbot populations are signs of partial success (Kerr and LeTendre 1991). Because of introductions, the fish community now contains more species than ever, but it is dominated by hatchery-reared salmonids. Stocking of salmonids by provincial and state agencies averaged slightly more than 8 million fish annually between 1984 and 1991 (Fig. 6.30). In

1993, 78% of the fish harvested by recreational anglers were stocked salmon and trout (224 000 fish), of which 43% were Chinook and Coho salmon (Savoie and Mathers 1994). The commercial fishery is confined primarily to Canadian waters at the eastern end of the lake. In 1992, approximately 584 000 kg of fish were harvested, with a market value of about $1 200 000 (see Table 6.3).

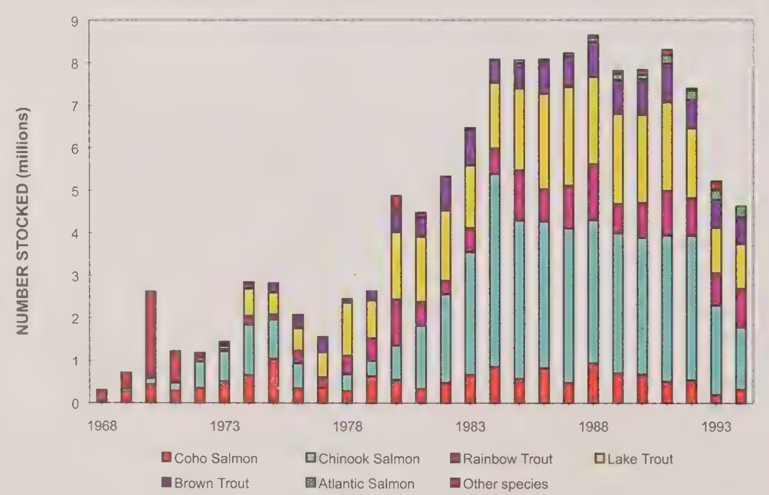
Hatchery and stocking programs using nonindigenous salmonids have inhibited progress towards a less intensely managed system using Lake Trout and other indigenous top predators to restore the original predator–prey balance. State and provincial agencies recently reduced salmonid stocking in an attempt to respond to declining productivity of the major forage species in Lake Ontario (Alewife and Rainbow Smelt) and establish a stable recreational fishery. Beginning in 1993 and continuing into 1994, combined stocking targets were lowered to 4.5 million fish (Bowlby et al. 1994). The response of Alewife and Rainbow Smelt to this reduced predator demand is being monitored.

Toxic contaminants

Lake Ontario receives over 1 500 kg of toxic chemicals per day, with the Niagara River accounting for 67%, urban runoff 13%, and sewage treatment plants 6% of the measured loadings (Thompson 1992). Cleaning up the Niagara River is therefore crucial to management of toxic substances in Lake Ontario. In 1973, the IJC designated the Niagara River as an Area of Concern because of concerns about toxic contamination of the river and Lake Ontario and the effects on human health and the ecosystem. Biomonitoring of Spottail Shiner fish has demonstrated that organochlorine chemicals are in the waters of the Niagara River (Fig. 6.31), whereas monitoring of caged mussels placed at various sites for three weeks in 1993 indicated that these chemicals come from dump sites in New York adjacent to the river, rather than from sources in the upper Great Lakes or atmospheric deposition. The chemicals are entering the Niagara River through groundwater discharges into the river and the urban drainage network.

Environmental agencies in Canada and the United States responded with the Niagara River Toxics Management Plan. It listed 18 persistent toxic substances found in the river (banned or restricted pesticides, organochlorines, PAHs, and commonly used metals) and called for a 50% reduction by 1996 of inputs of 10 "priority" chemicals. Because this goal will not be met, the Niagara River Toxics Management Plan framework is now being reexamined to consider possible new approaches. Separate Remedial Action Plans are also being prepared: the U.S. Remedial Action Plan focuses on toxic chemical problems in the Niagara River, whereas the Canadian Remedial Action Plan focuses on the Welland River. Continued reduction of toxic inputs to the Niagara River by removing the old wastes and contaminated soils in the New York dump sites is important to the future sustainability of the Lake Ontario basin.

Figure 6.30
Fish stocked into Lake Ontario, 1968–1994



Source: Orsatti and LeTendre (1994); J. Holmes, University of Toronto, personal communication.

Sustainability

Levels of contaminants in Lake Trout and in Herring Gull eggs of Lake Ontario were once the highest of all the Great Lakes except Lake Michigan (e.g., see De Vault et al. 1995). Conditions are improving, however, and they are now comparable to those in most other lakes (see Fig. 6.32; see also Fig. 6.19 and De Vault et al. 1995).

Nonetheless, several barriers stand in the way of full recovery of a healthy, self-sustaining ecosystem. The current pattern of population expansion in the Greater Toronto Area is not sustainable. There has been a substantial reduction in species and habitat diversity that may be difficult to reverse. Chemical inputs from sediments, landfills, industry, municipalities, agriculture, and the atmosphere and recycling of chemicals already in the environment continue to have harmful effects at all levels of the aquatic food web, and levels in aquatic biota have apparently stopped declining (Figs. 6.19 and 6.32; De Vault et al. 1995). Long-range atmospheric transport brings in pollutants generated outside the basin, such as toxaphene from the southern United States. Zebra Mussels, Purple Loosestrife, and invasions of other exotic species continue to have disruptive effects on the food web and on native species.

Many ongoing initiatives collectively may foster a recovery of the Lake Ontario ecosystem. Most of these efforts focus on local drainage basin management. The lake is a receiving body for almost 800 tributaries, and the cumulative effects of local abuses in these drainage basins appear downstream in the lake, its river mouths, and embayments. The Areas of Concern covered by Remedial Action Plans may be viewed as a network of sites where restoration is occurring. However, it may be impossible to extend the network to all areas where there are important environmental concerns, especially in heavily urbanized areas — some areas may simply be beyond rehabilitation (Kauffman et al. 1992). Most of the changes in the Lake Ontario basin since the late 1960s have been in a positive direction as a result of the shift to a stewardship mindset, yet it is not clear whether this will ultimately lead to a system that is sustainable.

St. Lawrence Lowlands ecoregion

The St. Lawrence Lowlands ecoregion (Fig. 6.33) had many features that made it a favourable location for human settlement — the river itself facilitated travel; its predominantly clay soil was rich and easy to cultivate; and wildlife was abundant, first for food and later for trade. However, as the population increased and human activities intensified, the environment became significantly altered.

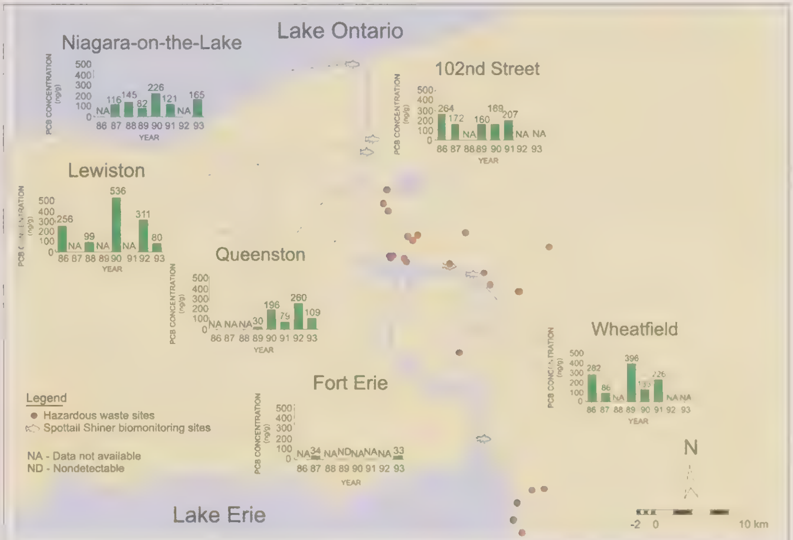
Effects of physical restructuring, dredging, and river traffic on riparian and aquatic habitats

The fringe of riparian habitats bordering the St. Lawrence River forms a shifting border between terrestrial and aquatic environments. Vast areas of lowlands surrounding the fluvial lakes are flooded each spring. Lake St. Pierre, for example, expands in area from 48 000 ha to 66 000 ha, an increase of nearly 38% (Burton 1991). The flooding of riparian land is of critical importance to wildlife (Fig. 6.34), particularly resident and migratory waterfowl and species of fish that spawn in the shallows covering the terrestrial vegetation (e.g., Northern Pike and Yellow Perch).

Physical changes to the aquatic environment have affected the entire river (see the section on "Physical restructuring" in this chapter). Structures such as the hydroelectric dams at Beauharnois and Cornwall have modified the flow regime and seasonal water levels, which appears to have resulted in changes in the abundance or distribution of some migratory fish species.

Figure 6.31

PCB concentrations in Spottail Shiners of the Niagara River



Source: Suns and Hitchin (1994), U.S. Environmental Protection Agency and New York State Department of Environmental Conservation (1994)

Figure 6.32

Trends in total PCB concentration in Herring Gull eggs in Lake Ontario, 1974–1995

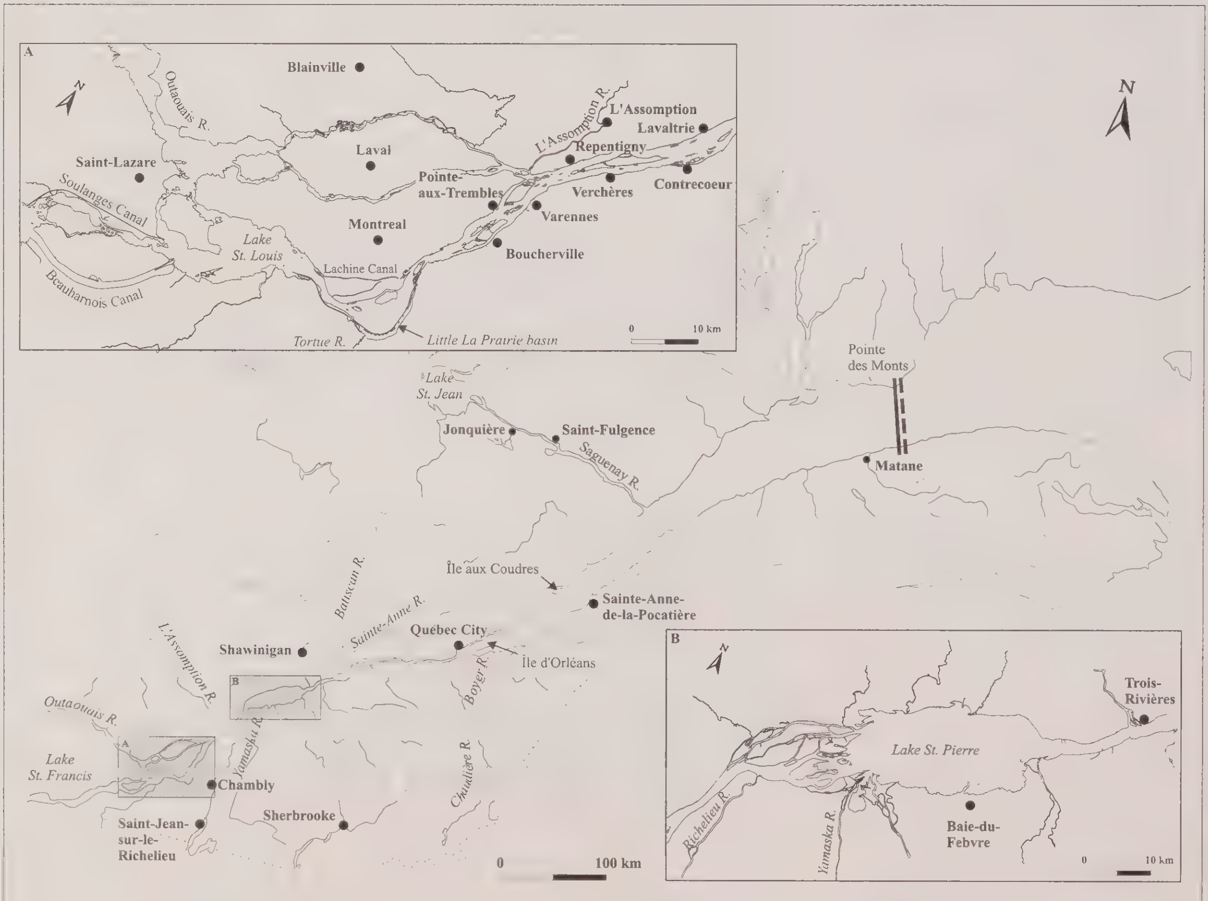
Note. PCB concentrations are averages of two Herring Gull colonies (Snake Island and Muggs Island)

Source. Bishop et al. (1992b), Pettit et al. (1994b), D.V. Weseloh, Canadian Wildlife Service, Environment Canada, personal communication

The enormous structures built in the St. Lawrence River have also had local impacts. In Lake St. Francis, which was transformed into a reservoir to supply the Beauharnois generating station, the water level was raised in the 1940s and then stabilized. Today, water levels fluctuate less than 40 cm, but in the opposite direction to the natural regime: the water level is low in the spring, increases in the summer, is low again in the fall, and peaks in the winter. This artificial regime affects the reproduction and development of plant and animal species, particularly those adapted to floods. The riparian vegetation around the lake has gradually altered over time to form dense but less diversified plant communities of less value to wild birds and fish (Armellin et al. 1993). There has been a gradual disappearance of species typical of floodplains (Pondweed, Bur-reed, and Wild Rice) (Ghanimé 1990). The fact that Lake St. Francis has only 56 species of fish (Lake St. Louis, located just downstream, has 80 species) may be attributed partly to the less diverse physicochemical composition of the water mass. However, it is believed that the cessation of natural flooding has also contributed to this lower diversity — the most abundant fish species in Lake St. Francis are those that do not require access to flooded land for spawning.

In sections of the St. Lawrence River typified by low alluvial islands interlaced with shallow channels, the construction of the Seaway led to increasing erosion due to the concentrated water flow, the faster velocity of currents, and the effects of vessel traffic. The erosive action of waves from a ship's wake breaking on shore is accentuated by factors such as the nature of the substrate forming the islands, ice abrasion, and the flow rate in the channel

Figure 6.33
St. Lawrence Lowlands ecoregion



Source: F. Boudreault, St. Lawrence Centre, Environment Canada, personal communication.

(Fig. 6.35). The wave action weakens the banks, and the substrate gradually slides into the water.

Wave erosion is most pronounced in the section of the river from Montreal to Lake St. Pierre, affecting the archipelagos of Boucherville, Repentigny, Varennes, Contrecoeur, and, above all, Verchères. Bertrand et al. (1991) documented that more than 75 km of shoreline are moderately or highly eroded by vessel-generated waves. Islands nearest the Seaway are the most severely affected. Shorelines are receding at a rate of 4.5 m annually in some locations and as much as 10 m at one site. Wave erosion is resulting in the loss of grassland, marsh, and wooded island habitats, some of which are extremely important breeding sites for ducks and other birds.

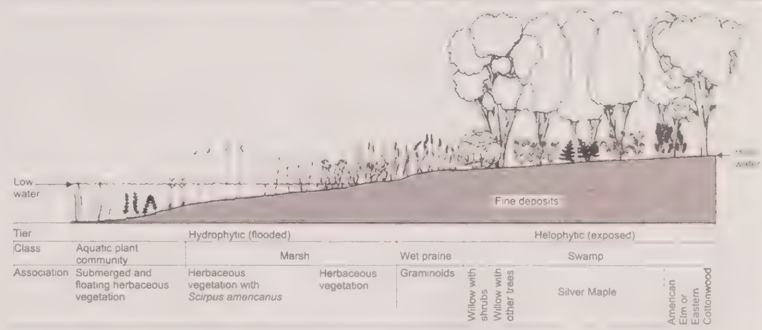
Vessel-generated waves also affect fish populations. By causing the resuspension of sediments in shallow areas, waves lead to the loss of spawning and nursery areas. Wave action is also thought to lead to lower species diversity in locations exposed to ships' waves than in areas sheltered from them.

Riparian and aquatic habitats have also been altered by the disposal of dredged materials, especially during the construction of the Seaway (see the section on "Physical restructuring"). Dredged materials were dumped either into the water, affecting benthic organisms, or onto island or other land sites, changing the elevation, relief, drainage, vegetation, and other habitat conditions. For example, as a result of the disposal of dredged materials, Narrow-leaved Cattail has gradually replaced Giant Bur-reed and River Bulrushes in some marshes. In other areas, Cattails are also displacing Stiff Arrowhead (Pilon et al. 1990).

In winter, icebreakers keep the navigation channel open so that ships can reach Montreal. This may affect certain species of fish that spawn beneath the ice. One such species, the Atlantic Tomcod, was once fished in winter at the mouth of the St. Maurice River and as far upstream as Lake St. Pierre. Today, however, the *petit poisson des chenaux* (little fish of the channels) occurs in only a few tributaries above Quebec City, the most important run entering the Sainte-Anne River (Hart et al. 1991).

Figure 6.34a

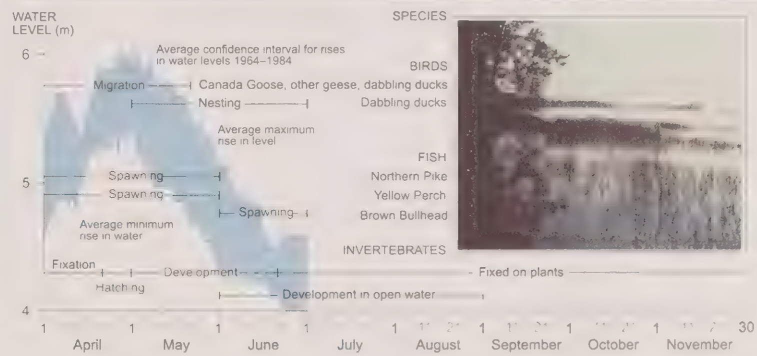
Profile of riparian vegetation and its use by fish and other wildlife



Source: Couillard and Grondin (1986), modified.

Figure 6.34b

Chronology of use of Lake St. Pierre floodplain



Source: Ministère du Loisir, de la Chasse et de la Pêche du Québec (1984); Lehoux et al. (1985); Verret and Savignac (1985).

An indirect environmental effect of the construction of the Seaway resulted from the relocation of many harbour and industrial facilities, which until then had been centred at Montreal. New port facilities were gradually built along the St. Lawrence to accommodate ocean-going vessels, increasing the number of industrial centres and points of discharge of polluted effluent.

Finally, heavy vessel traffic exposes much of the river and its shores to the risk of an accident (Public Review Panel on Tanker Safety and Marine Spills Response Capability 1990). The St. Lawrence Seaway is considered one of the most difficult waterways in the world to navigate because of its narrow, twisting channel and the presence of winds, currents, tides, and ice cover, which sometimes make manoeuvring difficult. Although ship traffic has declined in recent years, as many as 20 000 vessels still pass

through the St. Lawrence Seaway in a year, which is more than pass through the Suez and Panama canals combined. The transport of petroleum products by tankers poses the most serious risk, particularly in the Quebec City region, because the tankers have capacities of up to 160 000 t and draughts close to the maximum depth of the channel.

Long Sault to Beauharnois: the St. Lawrence River restructured

The stretch of the St. Lawrence River between Long Sault in the west and the Beauharnois dam at Lake St. Louis in the east at one time contained two series of rapids. The Long Sault rapids upstream of Cornwall and the Soulanges rapids downstream of Lake St. Francis prevented the passage of ships to Lake Ontario. Today, the rapids have been replaced by a series of reservoirs and dams, serving two large hydro generating stations (Moses–Saunders and Beauharnois) and one small one (Les Cèdres), and by four locks of the St. Lawrence Seaway. A human-made lake (Lake St. Lawrence) and an existing fluvial lake (Lake St. Francis) have become storage reservoirs for the Moses–Saunders and Beauharnois hydroelectric stations, respectively. The Moses–Saunders dam also regulates the water levels of Lake Ontario and the flow of the St. Lawrence. The 17-km-long Beauharnois Canal, which bypasses the Soulanges rapids, now carries 84% of the water flow of the river to the Beauharnois power station and serves as the shipping route of the Seaway. The flow through the former Soulanges rapids has been greatly reduced (see Fig. 6.6), and the rapids have been transformed into a number of recreational basins by a series of smaller dams (see Fig. 6.36 for a map of the area).

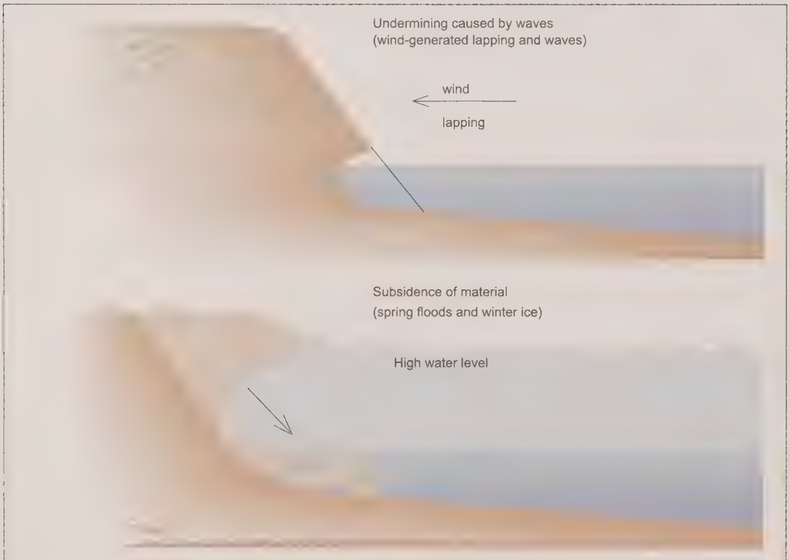
The restructuring of the river for ship transport and hydroelectric power has greatly changed the socioeconomic life of this region (e.g., see Box 6.7). At first, farms and towns were flooded, affecting aquatic habitats and the fishing and trapping that depended on them. Cornwall became an important textile centre in the 1880s, as the first Cornwall barge canal provided easy transportation of goods and the Long Sault rapids afforded cheap power for industrial plants. The construction of the St. Lawrence Seaway and the associated Moses–Saunders dam and power station changed the economic picture again, making possible the aluminum industry at Massena. However, Cornwall has declined as an important manufacturing centre, and today Domtar Fine Papers is the only major industry in Cornwall.

Equally profound were the changes in the regional ecosystems. The floodplain of Lake St. Francis has been practically eliminated, transforming ecological processes in the area of wetlands dependent on it. The flow of water is now concentrated in the shipping channel and greatly decreased outside of it. As a result, grassflats have expanded in the slow-moving water of Lake St. Francis. The construction of dams and the diversion of water from the original rapids have blocked fish migration routes (American Eel, sturgeon, etc.) and destroyed spawning sites. The eel ladder at the Moses–Saunders dam has only partially restored the migration route of this species, whereas the sturgeon population of Lake St. Francis is completely cut off from its traditional spawning grounds.

Industrial activities on both sides of the river have deposited large amounts of persistent organic chemicals and heavy metals in the sediments. Concentrations of some contaminants (e.g., PCBs in Spottail Shiners) are now among the highest in the Great Lakes–St. Lawrence system. A mercury chlor-alkali plant and slimicides used in the pulp and paper industry and a rayon plant in Cornwall were major sources of mercury, whereas Massena industries were the principal sources of PCBs.

In 1985, the international portion of the river was designated as an Area of Concern, and now two Remedial Action Plans (see Box 6.4) are in progress — one for Cornwall, Ontario, and the other for Massena, New York. In the Quebec portion of the river, Lake St. Francis is one of 23 Zones of Priority Intervention (see Box 6.8). The two Remedial Action Plans and the Zone of Priority Intervention have identified distinct problems, reflecting the local ecological characteristics of the river and specific human impacts. On the slow-flowing Cornwall side of the river, the per-

Figure 6.35
Erosion of shoreline due to shipping



Source: St. Lawrence Centre (1992a).

ceived problems include bacterial contamination, nuisance aquatic plants, aquatic habitat destruction, and mercury and other toxic contaminants. On the fast-flowing Massena side, PCB contamination from the industrial plants is seen as the major problem. In the Lake St. Francis area, the main concerns are with maintaining the large wetlands and a national wildlife reserve and their use for eco-tourism; the impacts of cottages, marinas, and other shoreline developments and of recreational boating; and keeping fish free of contaminants from upstream sources.

Assessment reports have been prepared for all three areas. Remedial Action Plan public advisory committees and a Zone of Priority Intervention committee have been formed, in which industry, local governments, and environmental and other citizen groups are involved to various degrees. The discharge of contaminants (PCBs in Massena and mercury and other heavy metals in Cornwall) has been greatly reduced, partly through the closure of facilities. Cleanup of contaminated sites on land and dredging of river sediments have also begun. Actions are under way to restore shoreline areas along the Cornwall waterfront and to control discharges of nutrients from non-point sources. In cleaning up the river, a concern for the two Remedial Action Plans is how best to deal with contaminated sediments. The process is somewhat more advanced in Massena than in Cornwall. In Massena, cleanups are proceeding under Superfund legislation of both the federal Environmental Protection Agency and New York State.

An ecoresearch project of the University of Ottawa has chosen to study this area, focusing on, among other things, the perceptions of the inhabitants about their health and the physical and chemical characteristics of the St. Lawrence River. A community-initiated environmental research facility, the St. Lawrence Institute, is also trying to establish itself in Cornwall, partly as a follow-up to the ecoresearch project. The city of Cornwall, the First Nations community of Akwesasne, and the University of Ottawa are partners in this initiative.

Agriculture in the Quebec part of the St. Lawrence basin

The predominantly clay soils of this region originally supported a forest dominated by various species of maple. Once cleared, the land proved easy to cultivate. Colonists gradually settled there, first along the banks of the St. Lawrence River, then along its tributaries. So that settlers would

Figure 6.36
Long Sault to Beauharnois

Source: Geomatics International, Burlington, Ontario. Prepared for the St. Lawrence River Remedial Action Plan team.

have access to the water, each parcel of land had a narrow frontage on the river, from which it extended a long way inland. This alignment still characterizes the rural landscape of the area today.

In recent decades, farms have become larger; production requirements and marketing standards have gradually forced producers to adopt intensive agricultural techniques. Crop production depends largely on mechanization, artificial drainage, and the use of fertilizers and pesticides. Livestock production is also becoming more intensive. From 1971 to 1991, numbers of pigs and poultry on farms grew by 110% and 45%, respectively, and livestock production became increasingly concentrated in certain areas (Ministère de l'Environnement du Québec 1993). The storage and field application of the large volumes of manures produced and the existence of local surpluses are persistent environmental concerns in some regions.

Box 6.7
The St. Lawrence River and the Aboriginal people — the view from Akwesasne

The St. Lawrence Seaway dramatically altered the lives of the local First Nations people. The biologically diverse river fishery changed to a lake fishery of pike, pickerel, bass, and perch. First Nations people lost large amounts of land as shorelines eroded and islands were seized. The patterns of ice cover on the river changed, making winter travel difficult. The control of water levels prevented spring floods, and marshes such as the Snye Marsh in Akwesasne (which once brought 30 000 muskrat pelts for the trappers) filled and lost their biological productivity.

The biggest change, however, came from the new industries that were attracted by the newly available hydroelectric power. Foremost among them were two large aluminum smelters. In the early 1960s, cattle on Cornwall Island became sickly, and Mohawk farmers could no longer maintain the healthy cattle herds that had sustained them and their families. Fluoride emissions from the Reynolds Metal Co. and Alcoa, near Massena, New York, were affecting vegetation and cattle. Despite the installation of $17.5 million of pollution control devices by Reynolds Metal Co. and subsequent decreased emissions, cattle were still affected by fluoride. Today, fluoride levels are about the same as in the late 1970s, and the cattle industry has collapsed.

In the 1970s, the Mohawk people of Akwesasne began to worry about the dangerously high levels of heavy metals and organochlorine compounds being found in the St. Lawrence River. In 1978, the Mohawk Council of Akwesasne recommended that women of child-bearing age and children under 15 not eat any fish from the river. Health studies carried out in 1985 and in the 1990s showed that the burden of contaminants in Mohawk people who refrained from consuming fish from the river was much lower than in people who did consume fish. The studies are continuing. However, the impacts of this recommendation on the community have been devastating. Fishing is no longer a way of life, and fish are no longer the primary source of protein for the community. The former high-protein diet of the Mohawk people has changed to a high-carbohydrate diet, with a resulting dramatic rise in diabetes. Today, 75% of the population over the age of 35 suffers from some type of abnormal glucose tolerance: this in a community where there was no diabetes before 1945.

As the traditional economies of farming, hunting, trapping, and fishing disappeared, nontraditional economies expanded, and the community-based system of support and distribution started to disintegrate. The resulting tension in the community led, in 1990, to violence and death. Since 1990, the Canadian and U.S. governments have spent an estimated $500 million on police activities, money that could have more wisely been spent on environmental cleanup.

Increasing industrialization and other developments have led to similar environmental degradation along other segments of the St. Lawrence River. First Nations people, who depended on its resources the most, have been affected the most. In response, First Nations governments have established environmental departments to learn about the state of the river and to be aware of the consequences. The Department of the Environment for the Mohawk Council of Akwesasne was created in 1976, and others can now be found at St. Regis Mohawk and Kahnawake. Since the early 1970s, groups such as the U.S. Environmental Protection Agency and Environment Canada have been making efforts to work with First Nations people.

The IJC has identified the St. Lawrence River at Akwesasne and Cornwall as an Area of Concern. The Mohawk Council of Akwesasne invited all of the parties to a meeting in St. Regis, Quebec, to discuss the local Remedial Action Plan and how the Mohawk would be involved. However, the process was not a satisfying experience for the Mohawk people, who felt that the plan did not include them in a fair and equitable way.

Other initiatives have been more successful. In the community-based EAGLE (Effects on Aboriginals from the Great Lakes Environment) Project, Akwesasne, with many other First Nations communities, is working with Health Canada to look at the biological, social, and economic effects of contaminants (see Assembly of First Nations 1993). Akwesasne is also a partner in other joint initiatives: the community-based St. Lawrence Institute in Cornwall, which studies the environment of the river, the ecoresearch program of the University of Ottawa, projects with several other universities, the Eastern Ontario Model Forest project, and plans for joint fisheries work with eastern Ontario anglers' associations. These efforts enhance the empowerment of the First Nations communities and create respect and trust between First Nations and their non-Aboriginal partners.

Source: H. Lickers, Department of the Environment for the Mohawk Council of Akwesasne.

The intensification of agricultural practices has had major environmental effects in some areas. Landscapes have been altered, with natural ecosystems being largely eliminated in certain areas to accommodate immense expanses of agricultural land (Boutin et al. 1994). To make use of the largest possible area and to facilitate the manoeuvring of farm machinery, shrubs bordering watercourses have been removed and low areas and wetlands drained and reshaped. Fields have been tilled to within a few metres of rivers. Cultivation practices that leave the soil denuded without a layer of crop residue in winter, furrows oriented in the direction of the slope of the ground, and compaction of the soil by farm machinery have caused heavy surface runoff and soil loss to waterways. Finally, the elimination of natural windbreaks has exposed fields to wind erosion.

In recent decades, there has been a significant increase in corn production in Quebec, from 55 800 ha in 1971 to 293 800 ha in 1991 (Ministère de l'Environnement du Québec 1993). New, faster-growing corn cultivars (see section on "Changes in technology and energy use") have made corn production possible in regions with growing seasons that previously had been too short for this crop. As a consequence, a shift of corn production from the Lake Erie Lowland ecoregion to the St. Lawrence Lowlands ecoregion has been occurring over the last 20 years (see Figs. 6.1a and b). This has been accompanied by a large increase in fertilizer and pesticide use in the St. Lawrence Lowlands ecoregion and in Quebec as a whole (see Fig. 6.4). When corn is first introduced, it is also a frequent practice to grow it in monoculture, a practice leading to increased risk of soil erosion and other environmental impacts. Crop rotation, cover crops, and other more sustainable practices (as seen now in the Lake Erie Lowland ecoregion) take longer to be established. The predominance of large uniform fields of grain corn and other cereal crops can cause changes in the composition of wildlife communities. This has been extensively documented in the case of birds: monoculture seems to benefit birds that like open areas. Depending on the time of year and state of the fields, monoculture also appears to invite incursions from opportunistic species, such as Ring-billed Gull and Rock Dove (DesGranges et al. 1994). Red-winged Blackbirds, European Starlings, Brown-headed Cowbirds, and other blackbirds have learned to take advantage of the abundant food source and feed in the fields by the thousands (GREBE Inc. 1990).

Bird surveys provide an indication of the extent of the changes to bird populations resulting from modifications in the rural environment. There is a greater abundance and diversity of birds in areas where a mosaic of habitats forms a mixed landscape than in extensively cultivated areas where the ground is laid bare and ploughed every year (DesGranges et al. 1994). Wooded areas and wetlands, even if they are small, promote a greater diversity on farms, because they support species that are not necessarily associated with agricultural environments (Boutin et al. 1994).

In some regions where the area of pasture for dairy cattle has declined, there has been a decrease in the abundance of

Box 6.8
Zones of Priority Intervention along the St. Lawrence and the Saguenay

The Zones of Priority Intervention (ZIP) program, which in many ways is similar to the RAP program, started in 1988–1989 as two separate but parallel initiatives. Strategy St. Lawrence was a public action program undertaken by a number of nongovernmental organizations and coordinated by the Union québécoise pour la conservation de la nature. Its main objective was the cleanup of 22 sites contaminated by industrial wastes. The other was the commitment of the governments of Canada and Quebec under the St. Lawrence Action Plan to clean, conserve, and restore the river.

In 1990, with the goal of harmonizing the two programs, the governments of Canada and Quebec began to prepare state of the environment reports for the 23 ZIPs. In 1992 and 1993, the nongovernmental organizations and the two governments jointly organized consultations to present and discuss the state of the environment reports and define priorities. Priorities were to be based on local perceptions of problems, aided by the state of the environment reports.

In 1993, with St. Lawrence Vision 2000, the second phase of the St. Lawrence Action Plan, a specific program was created to foster public participation in its objectives. An agreement was reached between Stratégie Saint-Laurent Inc., a nongovernmental organization, and the two governmental partners of St. Lawrence Vision 2000 to participate jointly in the ZIP program.

The ZIP program consists of three main components: state of the environment reporting, consultation, and an action plan. The chief roles of the partners are as follows: the governments produce the state of the environment reports, provide technical assistance to Stratégie Saint-Laurent and the local ZIP committees, and fund specific activities on an annual basis. Stratégie Saint-Laurent is responsible for the creation of the ZIP committees and the coordination of their activities; it acts as the official interface between the governments and the public. The ZIP committee is the local focal point, organizing the consultation activities and the preparation of an action plan for future interventions, based on priorities identified locally. The ZIP committee is made up of representatives from a broad cross-section of the population; everyone is invited to participate, and there are no predetermined seats, the whole process being open to any participant willing to help move priority cases into action. As of 1996, state of the environment reports have been prepared for 10 ZIP areas, 9 ZIP committees have been formed, consultations have been completed for 7 ZIPs, and action plans have been defined in 2. It is estimated that all action plans will be completed by the year 2000.

Savannah Sparrows, Bobolinks, Killdeers, Eastern Meadowlarks, Red-winged Blackbirds, and other species that normally nest in or around pastureland. However, American Robins, Song Sparrows, Yellow Warblers, American Crows, and other species seem to have benefited from the natural regeneration of vegetation on abandoned agricultural fields (DesGranges et al. 1994).

Shared use of available space by wildlife and farmers sometimes leads to conflicts. For instance, the construction of dikes at the ends of fields, which hastens the spring planting of land that would otherwise be inundated by floods, reduces waterfowl habitat and limits the spawning and nursery areas available to several species of fish. The practice has been the source of friction between farmers and wildlife management organizations, particularly in the Lake St. Pierre region. Solutions to such conflicts include the integration of several different land uses, in this case by installing structures that control water levels and the duration of flooding. Several projects of this nature are under way along the St. Lawrence River.

There are further examples of the coexistence of wildlife and agriculture in the region. Many St. Lawrence islands have long been used as pasture in the summer months. It was recently realized that the trampling of wetlands by cattle was having adverse effects on waterfowl reproduction on some of these islands. Simple measures to control livestock movements resulted in an immediate improvement in duck hatching success (Bélanger 1993). Similarly, a program was established to compensate farmers for crop losses due to the spring invasions of fields by Greater Snow Geese (Reed 1990). Currently being tested in the Baie-du-Febvre region, south of Lake St. Pierre, the solution consists of attracting the birds to selected cornfields on which crop residue is left from the previous year through the practice of zero tillage (E. Coté, Agriculture and Agri-Food Canada, personal communication).

The effects of intensive agriculture on the aquatic environment are indisputable. During heavy rainfall or snowmelt, large volumes of suspended matter, fertilizers, and pesticides are transported by surface runoff into small rivers, altering the aquatic ecosystems and the composition of the biological communities in them. Farm chemicals applied to fields with coarser-textured soils take a different route: they percolate with precipitation down to the water table, which they contaminate to such an extent that wells can become unusable for irrigating some sensitive crops (Giroux 1993), and concerns also arise about the use of this water for human and livestock consumption.

Draining wetlands and some other practices adopted to increase crop yields deprive waterways of holding basins that are essential for moderating the extremes of high- and low-water periods. A rise in flood severity can lead to an increase in scouring and bank caving in bends along a river's lower reaches, especially where clay beds prevail. Increased erosion accelerates soil loss to the river and sea.

When disturbances to aquatic communities are localized, the effects on biota are also usually localized. In some cases, however, the impacts are felt beyond the borders of the basin affected. For example, the population of Rainbow Smelt along the south shore of the St. Lawrence estuary has been greatly affected by the degradation of its main spawning grounds in the Boyer River (Robitaille and Vigneault 1990; Trencia et al. 1990). This Rainbow Smelt population traditionally concentrated its spawning activity in the gravel and pebble beds of this small south-shore tributary (A. Michaud, Planification des équipements, Hydro-Québec, personal communication). Today, Rainbow Smelt are completely absent from the Boyer River. They survive in the estuary only by continuing to spawn in less favourable areas. The degradation of the Boyer River is primarily the result of agricultural activities in its drainage basin. Today, the pebbles on its bed are covered with stringy algae that can no longer support the adhesive eggs of the Rainbow Smelt; the presence of filamentous algae on spawning sites is one hypothesis that has been put forward to explain the disappearance of Rainbow Smelt from the Boyer River.

A Boyer River restoration movement has been launched in the hope that the Rainbow Smelt will one day return. Provincial ministries, the federal Department of Fisheries and Oceans, municipalities in the region, and a federation of local farmers' organizations (Union des producteurs agricoles) are jointly involved. The plan aims to use an ecosystem approach to consider and manage all activities in the drainage basin. Farm practices (manure management, changes in fertilizer use, protecting riverbanks from cattle, etc.) are the most important aspects of the program. The case of this one small river is representative of the types of changes that are occurring in the St. Lawrence basin, where farmers are becoming increasingly aware of the effects of agricultural practices and are taking steps to mitigate them (Union des producteurs agricoles 1993).

Government organizations and farmers' associations now promote practices based on sustainable agriculture. Strategies being adopted to strike a balance between agricultural needs and the health of the environment include the use of organic fertilizers, the appropriate use of pesticides, practices favouring the conservation and restoration of agricultural soils, and structures that allow wildlife and agriculture to coexist.

Urbanization: the example of Montreal

Until the 1950s, industrial activity in Montreal centred on the harbour, the railway terminal, and the Lachine Canal. For decades, industrial plants discharged effluents into the Lachine Canal and the harbour, where, in the absence of a current, they formed a layer of highly contaminated sediments several metres thick (Environment Canada 1993). Along the entire length of the Island of Montreal, outfalls discharged domestic, commercial, and industrial sewage into the river (Fortin 1994). The water quality of the St. Lawrence River deteriorated in terms of both bacterial count and contaminant loadings as it flowed past the city (Fortin 1994).

With the construction of major road arteries in the 1960s, working-class districts on the Island of Montreal declined and the suburbs expanded, first on the east side of

the island, then on the south shore (Ville de Montréal 1992). With the displacement of the population, industry also relocated to the suburbs (Jourdain and Bibeault 1994). Urban sprawl seriously encroached on high-capability farmland and forests (Jourdain and Bibeault 1994).

Today, the section of the St. Lawrence River flowing past metropolitan Montreal is the most altered stretch of the entire river. Between the Lachine Rapids and Pointe-aux-Trembles, the natural shoreline has been replaced by an uninterrupted series of walls, backfill, and wharves (Clavet 1993). Most of the natural riverbank environments have been obliterated by roads, bridges, power transmission lines, residential and industrial buildings, parks, and marinas; both the land and adjacent waters have been degraded. However, a few fragments of natural environment have survived near the city. Sections of shoreline remain in their original condition, a few plant communities are virtually intact, and there are even heron colonies on several of the islands in the St. Lawrence River to which access is limited. The loss of forests due to urban sprawl seems to have slowed down in recent years. To address the water quality problems, the Montreal Urban Community has built water treatment plants, and swimming is once again possible at several locations. City-dwellers have come to value trees and green spaces. The time may be right for incorporating the conservation and enhancement of the natural environments that have survived into regional planning.

St. Lawrence estuary

Gateway to the continent and transition zone between ocean and river, the St. Lawrence estuary is the trunk line of the entire Great Lakes–St. Lawrence system. It is the pathway and acclimatization zone for all fish species that migrate between the sea and fresh water to complete their life cycle. The fresh water that ends up here reflects — in physicochemical properties and contaminant loadings — the inflows of each part of the system.

The middle estuary and zone of maximum turbidity

The freshwater and saltwater masses in the estuary do not mix immediately. Owing to differences in salinity, they have different densities, and the fresh water tends to stay near the surface, above the denser salt water. Mixing takes place gradually through tidal action and the currents that it produces in various flow channels.

Between Île d'Orléans and Île aux Coudres, there is a zone of sediment mixing that oceanographers call the maximum turbidity zone. Tides in this section cause reversals in current flow and resuspension of particulate matter, which is brought into the zone by the St. Lawrence River at a rate of approximately 4 million tonnes annually (Silverberg and El-Sabh 1990). Concentrations of suspended particulate matter in the water here are in the range of 10–450 mg/L (d'Anglejean 1990). This compares with a range of 2–3 mg/L upriver at Cornwall (Leclair et al. 1992).

Freshwater phytoplankton and organic debris carried by the river end up in the maximum turbidity zone, where they decompose, resulting in intense bacterial activity. This, in turn, promotes a high density of zooplankton. As contaminants tend to remain bound to these particles, many contaminants enter the food web in the maximum turbidity zone (Gagnon et al. 1990). They are then biomagnified as they are transferred to organisms higher up in the food web, such as predatory fish.

The maritime estuary and Saguenay Fjord

The influence of freshwater inflows from the river on the biological community dissipates a few kilometres downstream from the maximum turbidity zone. The mouth of the Saguenay Fjord, on the north shore, marks the upstream boundary of the maritime estuary, which opens into the sea at its other end.

A fjord is a deeply excavated glacial-trough valley that is later submerged by the sea. The Saguenay Fjord is divided into three basins, the deepest of which (280 m) is also farthest from the estuary (Fig. 6.37). A sill at the mouth of the fjord limits exchanges between saltwater masses at the bottom of these basins and those of the estuary. Water from the Saguenay River flows into the fjord at Saint-Fulgence, then slides along the surface to the estuary without mixing with the much colder and more saline deeper layers.

This deep pocket of marine habitats, which is relatively isolated from the estuary and gulf, is home to animal species that are normally found only in Arctic and sub-Arctic waters. They include such fish species as Arctic Cod, Atlantic Poacher, Polar Eelpout, Fish Doctor, Arctic Staghorn Sculpin, and Greenland Halibut. This enclave of animal populations is a vestige of the last ice age.

The habitat of these animals is not as pristine as it was 10 000 years ago. For many years, industrial effluent contaminated primarily by mercury and PAHs has been transported into the fjord. These substances settle in sediment at the base of depressions (Pelletier 1994), where they can remain for a very long time. However, as a result of pollution control measures taken in the 1980s, concentrations of toxic substances in industrial effluent have declined, and less contaminated sediments are gradually covering the more highly contaminated sediments (Fig. 6.38). It is hoped that this process will gradually reduce the risks to bottom-dwelling organisms.

At the mouth of the fjord is an area heavily used by baleen whales (Blue Whale, Finback Whale, and Minke Whale), which come to feed and rebuild their fat reserves. They are attracted to the site, to the delight of whale-watching tourists, by the presence of pelagic crustaceans (especially euphausiids, also called krill, and copepods) that are transported to and trapped in the area.

One recently advanced hypothesis to explain this process has to do with the upstream circulation of the deep layer of the water masses, which balances the downstream flow of fresh and brackish waters in the surface layer (Simard 1994). According to this hypothesis, the deep water layer carries the crustaceans very

slowly from as far away as the gulf to the head of the Laurentian Trough at the mouth of the Saguenay. There they form dense aggregations that can reach 100 m in thickness and several kilometres in length. This superabundance of food attracts not only whales but also several species of pelagic fish (Atlantic Herring, Capelin, and Northern Sand Lance), on which the whales also feed. The remarkable environment of the Saguenay Fjord and the head of the Laurentian Trough will form part of the Saguenay National Marine Conservation Area being established by Parks Canada.

The Beluga

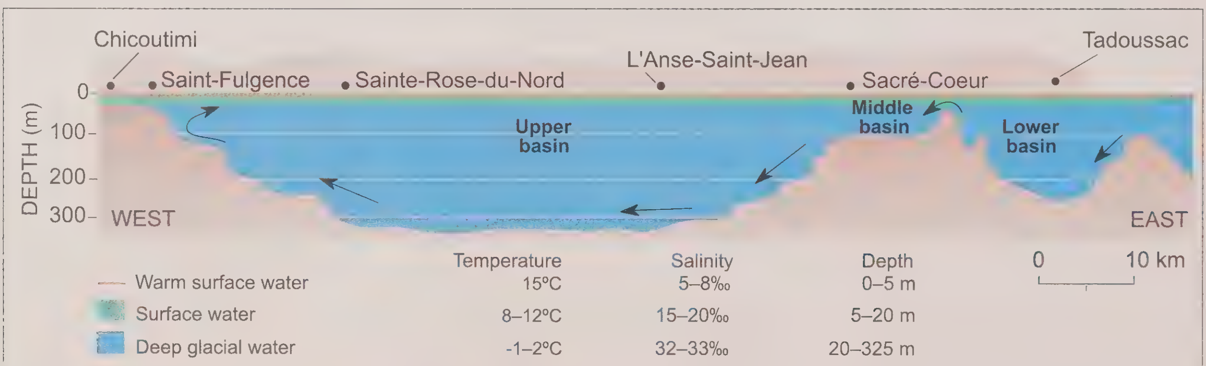
One of the special features of the St. Lawrence estuary is its resident population of Beluga (White Whale), a small, toothed whale with opportunistic feeding habits (Lesage and Kingsley 1995), which is characteristic of circumpolar seas (see Chapter 9). Still abundant at the turn of the century, Belugas fed in the spawning and gathering areas of certain species of fish (Lesage and Kingsley 1995). They also made regular incursions into freshwater environments upstream of Quebec City in pursuit, it is believed, of schools of fish swimming upriver (F. Gingras, commercial fisherman, Saint-Nicolas, Quebec, personal communication).

The Beluga was cursed by river fishermen, who accused it of chasing away fish. At one time, it was believed that the prospects of commercial harvesting of this marine mammal were promising; starting in the early 1700s, several attempts were made to harvest it on a systematic basis. However, catches remained sporadic and too variable (Reeves and Mitchell 1984). Only three sites (Ouelle River, Sainte-Anne-de-la-Pocatière, and Île aux Coudres) were used on a somewhat regular basis until the mid-1900s. Takers were easily found for its skin and especially its very fine oil.

Commercial Beluga hunting stopped in the mid-1950s. An undocumented hunt, which continued until it was definitely stopped in 1979, probably restrained the population from increasing or continued to reduce it. In the late 1970s, the population was estimated to be in the low 300s and rapidly declining. This evaluation was taken seriously enough for the population to be given endangered status by COSEWIC. In the late 1980s, continued aerial surveys replaced this index estimate by a figure of near 500 animals. This compares with the estimated 5 000 Belugas in 1885 (Reeves and Mitchell 1984). Béland (1996) postulated that their survival rate, reproductive success, and the appearance of diseases considered rare in whales are affected by the high concentrations of contaminants in their tissue (Table 6.16). The Beluga, at the top of the food web in the estuary, is most likely to biomagnify those contaminants to dangerous levels. Mirex in Beluga tissues is an example, thought to be introduced into the diet of the Belugas by contaminated eels migrating downstream from Lake Ontario (Comba et al. 1993).

The most recent Beluga survey (25 August 1995) and a reevaluation of earlier data (Kingsley 1996) have given some signs of hope for the eventual recovery of this population. The survey resulted in an estimate of 705 ± 108 individuals for 1995, a number corrected by 15% for underwater Belugas ("population index"). Smoothing this estimate together with earlier estimates, and in light of our knowledge of Beluga reproduction in general, produces a population index of 640–650 ± 50 individuals (Kingsley 1996). As the estimation method underestimates the number of Belugas diving during the count, the actual number may be substantially higher. A comparison of all the surveys over the last 18 years (Fig. 6.39) is also suggestive of a slow upward trend (3–4% per year) in their population (Kingsley 1996). Recent measurements by Muir et al. (1996a, 1996b) (Table 6.16) also suggest that the concentrations of some contaminants may be slowly decreasing.

Figure 6.37
Saguenay Fjord



Note: ‰ = parts per thousand.

Source: *Le Soleil*, March 18, 1989, Section D, p. 2, modified.

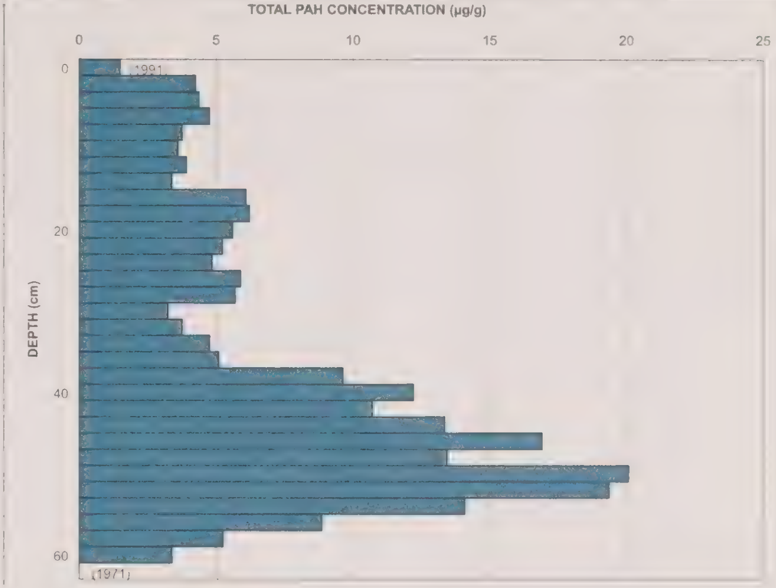
Until now, no research has been carried out on the capacity of the estuary to support Belugas in terms of the abundance and availability of fish species on which they might feed. The structure of estuarine fish communities has been severely altered by a large number of different types of disturbances, originating in the region itself and upstream (Robitaille et al. 1988). The Beluga may well be suffering from a reduction in the abundance of some of its prey.

As well, there are some data suggesting that increased vessel traffic may have disturbed Belugas and restricted their use of their habitats (Lesage 1993). They are disturbed less by large ships and ferries with regular routes than by small, noisy pleasure craft, whose routes are unpredictable. Such activity might disturb females with calves and limit the use of some feeding areas. Guidelines have been imposed to reduce the impact of pleasure boating in this area.

Finally, the occasional observation of isolated individuals, outside their normal distribution area, points to the possibility

Figure 6.38

Concentrations of PAHs in a sediment core sample from Saguenay Fjord, 1991



Note: Sediments at a depth of 60 cm in the core were deposited in about 1971.

Source: Pelletier (1994).

Table 6.16

Concentrations of organochlorine contaminants in Belugas of the Eastern Arctic and the St. Lawrence River estuary for various years

		Eastern Arctic, 1993–1995			St. Lawrence, 1993–1994			St. Lawrence, 1987–1990	St. Lawrence, 1986–1988
	Sex	Number	Mean	Range	Number	Mean	Range	Mean	Mean and variation
Sum of PCBs	Males	21	5.01	1.42–21.7	7	79.2	49.3–135	78.9	
Aroclor 1254:1260		21	nd	nd		97.2	54.8–145	86.0	190±79
Sum of DDT		21	4.81	1.74–10.6		47.6	20.1–63.7	76.3	150±77
Mirex		21	0.05	0.02–0.14		1.0	0.66–1.93	0.3	0.8±1.2
Age (years)		16	9.75	1.5–22		19.2	3.5–27.5		
Sum of PCBs	Females	22	2.35	0.58–9.83	9	61.1	15.3–181	29.6	
Aroclor 1254:1260		22	nd	nd		69.1	13.5–174	30.1	
Sum of DDT		22	2.89	1.11–7.48		32.4	5.54–76.7	17.5	
Mirex		22	0.04	0.01–0.11		0.9	0.2–2.4	1.1	1.4±0.9
Age (years)		17	11.7	3.5–24		19.5	10–33		

nd: not detectable

Notes: 1. Concentrations are in µg/g (ppm) measured in blubber and normalized to 100% lipid content.

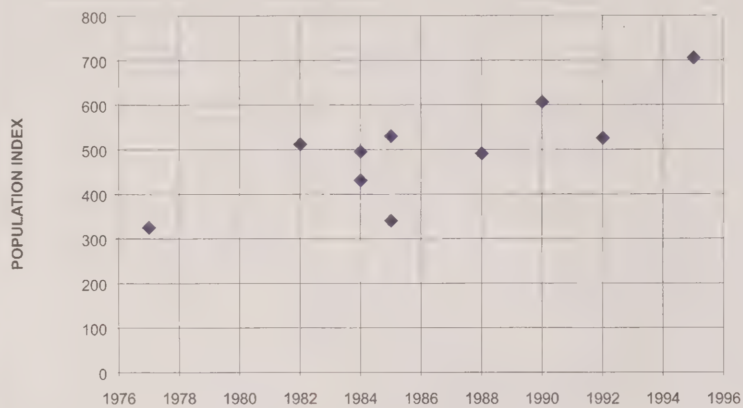
2. Means for concentrations are geometric means, for ages, arithmetic means.

3. Arctic locations: East and West Hudson Bay, Southeast Baffin, and Cumberland Sound stocks; ages were not available for all Arctic animals.

4. In males of the species, there has been a statistically significant decrease in DDT and Aroclor 1254:1260 levels from earlier concentrations; concentrations in females are more variable and are thought to depend on their reproductive history (Muir et al. 1996b).

Source: Muir et al. (1996a, 1996b).

Figure 6.39
Trends in the St. Lawrence Beluga population, 1977–1995



Notes: 1. Numbers were estimated from aerial photographs or visual counts from a boat or airplane.
2. The population index is arrived at by correcting the numbers of observed Belugas for the estimated fraction diving and for Belugas outside the observation area. The population index is considered to be a low estimate of the existing population (St. Lawrence Beluga Recovery Team 1995).

Source: Kingsley (1996).

that emigration, notably in spring, may be reducing the population by two or three individuals each year (Sergeant and Hoek 1988).

Sustainability in the Great Lakes–St. Lawrence Basin

This chapter has described the state of the environment in the drainage basin of the largest linked freshwater system in the world. The stresses on the ecosystems in this basin and their immediate causes have long been known. For the freshwater ecosystems, the list includes waste disposal in the waters, restructuring of shores and lake- and riverbeds to serve navigation and power generation, overfishing, the influx of exotic species through the "open door" of the St. Lawrence Seaway, and the legacy of persistent, bioaccumulating toxic chemicals deposited from near and afar (Francis and Regier 1995). The terrestrial ecosystems and the air are further stressed by agriculture and urbanization. For a while now, questions have been raised about how the stresses and their impacts could be dealt with, which ones could and would be tolerated, and to what degree. Some answers to these questions are seen in the binational agreements and treaties in effect in the basin, as well as in agreements and initiatives at lower levels of government, in technological innovations, and in the wide range of community-based projects.

Some priorities for achieving sustainability

Priorities for addressing the stresses on the basin's environment include:

- ensuring the sustainability of the spreading network of urban and suburban centres, many of which are located in close proximity to agricultural areas;
- making intensive agriculture sustainable;
- pollution prevention;
- dealing with persistent toxic substances (including understanding long-range air transport, the subtle effects of contaminants, and how to eliminate them from sediments and biota); and
- protecting remaining habitats and maintaining the biodiversity of indigenous species.

These priorities are linked in many ways. Moreover, conditions are constantly changing, so understanding can only be temporary in most instances. Integrated responses are needed — responses in which all levels of governance and many institutions are involved in taking a holistic, ecosystem approach.

This section is presented in six segments. The first two discuss the human influences that have brought the largest transformations to the terrestrial component of the basin: agriculture and rural society, and urban life and its ramifications. The third segment examines climate change, a subject indicative of the risks of changes whose exact nature cannot be predicted. The fourth segment provides an environmental synopsis for the Great Lakes–St. Lawrence basin as a whole, with particular emphasis on the huge aquatic ecosystem that dominates the basin, and the fifth segment briefly summarizes some of the main issues surrounding sustainability in the subbasins discussed in this chapter. The final segment looks at some of the processes that have been initiated in response to the challenges.

Agriculture and rural life

Intensive agriculture brings about a radical transformation of the landscape, and nowhere in Canada is agriculture as intensive as here, where 37% of Canada's agricultural products are generated on 9% of its farmland. In the basin, as elsewhere in Canada (see Chapter 11), farming has intensified and become more specialized. Cropland now makes up over 65% of total farmland, crops and livestock tend to be concentrated in different areas, and fewer than 9% of farms account for almost 50% of sales.

In considering the sustainability of agriculture and rural life, three types of areas should be examined (Research Sub-Committee of the Interdepartmental Committee on Rural and Remote Canada 1995):

- the areas of intensive production;

- the rural, but less and less agricultural areas at the perimeters of large cities; and
- the more remote and fringe areas.

In the most fertile areas, intensive, specialized crop cultivation is practised. The main crops (corn and soybeans) are primarily grown for livestock feed, and the demand for them depends on the demand for meat and dairy products. Some livestock production (for meat, dairy products, and eggs) is equally concentrated (such as on feedlots and poultry farms), but on less fertile soil. The Mixedwood Plains ecozone is also the centre of Canada's fruit and vegetable production. These and other specialty products (e.g., "organic" products, mushrooms, and ginseng) find a market in the large population nearby. Continental and global market forces, changes in technology, and consumer preferences drive this agriculture. Products are limited to a few that can best be grown here (corn, soybeans, dairy, and meat); others that can be more economically produced or processed elsewhere (grapes, tomatoes) are slowly disappearing. As a result of technological changes (such as new corn cultivars), production patterns have changed: corn, for example, which used to be grown primarily in the southwest, is now increasingly grown in the east.

This type of intensive agriculture has the potential to exhaust the natural resources on which all agriculture is based and to affect surrounding ecosystems. Contamination of surface waters and groundwater and the potential of (possibly irreversible) depletion of soil productivity are the main threats. Corn monoculture, where practised, can be particularly damaging (soil erosion and compaction, loadings of pesticides and fertilizers to the environment). Concentrated livestock operations can have difficulty with manure management, and manure can be another source of serious water pollution.

Control of soil erosion to preserve soil productivity and control pollution has been the focus of conservation efforts. Everywhere, but particularly in the traditional centre of corn production in the southwest, there has been an increase in soil conservation practices such as crop rotation and conservation tillage. Conservation and zero tillage can even have immediate economic benefits. However, there seems to be a time lag between changes in production patterns and the general acceptance of conservation practices: the newest corn-growing areas still have lower rates of such practices and seem to be most at risk from soil erosion.

The development of new, less persistent, and more specific pesticides is bringing about a significant reduction in pesticide loadings to the environment. Integrated pest management and variable rate technology for fertilizer applications are being promoted by various farm programs for their economic as well as environmental advantages. Some aspects, however, are highly technical (tracking systems to identify optimum application rates and timing, differentiated spot applications, etc.), and it is not known yet how widely accepted they will become. A study by the Science Council of Canada (1992) suggested a deregulated and high-tech form of agriculture (with some aspects of regulation and publicly sponsored research and planning) as the most likely scenario for future sustainability.

"Organic" or "ecological" farming provides a small but growing number of farmers with both a profitable "niche" market and a wholesome environment for their families. Case studies from three ecological farms in the Mixedwood Plains ecozone (one in the Nicolet region near Lake St. Pierre, one near Georgian Bay, and one near Chatham in the southwest) indicated that personal commitment, access to information, instruction and professional advice, and farm support groups were crucial factors in the farms' success. All three farmers, whose operations ranged from a small mixed farm to a large cash crop farm, emphasized the economic advantages. However, without the stability provided by milk management boards, it might have been difficult for the two smaller farms to convert to ecological farming (Tisdall 1992).

On prime agricultural land around large metropolitan areas, the tendency is towards increasing rural populations but decreasing numbers of people working on farms. Instead, residents depend on the urban economy or on local service industries. What farming occurs here is increasingly sharecropping on land temporarily leased from developers. Conflicts between farming and residential interests are frequent. The new residents in these "rural nirvanas" object to the smells, dust, and noise of farming, but they bring environmental stresses of their own, as well as adding to the pressures on local infrastructure. Ways are now being explored to ensure a more structured growth, using zoning for agricultural land and protected areas and land use planning as tools (see also the following discussion on "Urban life").

The areas that border the Boreal Shield and Atlantic Maritime ecozones are experiencing decreasing populations and increasing average age of the population. There are also some signs that a subsistence economy, partially uncoupled from the dominant economy, may be developing in these regions and that the regions may be beginning a period of regreening and natural reforestation (Moss and Davis 1994; McKibben 1995).

Urban life

The Great Lakes–St. Lawrence basin contains the largest urban and industrial complex in Canada. The region has traditionally accounted for three-quarters of the country's manufacturing output, but it is now undergoing a structural transformation and partial deindustrialization (Francis and Regier 1995).

Dense transportation corridors link the basin's cities with one another and with the eastern United States. Networks of railroads and highways, which largely replaced the old water routes, are themselves being complemented and supplanted by air corridors, fibre optic cables, satellites, and other communication corridors that are less restrained by physical limitations. Together, these many kinds of corridors are dominant forces in shaping

urban settlement patterns, trade, and the structure of the economy. With these evolving conditions come different environmental impacts.

The urban harbours along the St. Lawrence Seaway remain among the largest local sources of contamination of the aquatic system. They are also the subject of continuing cleanup efforts (see Boxes 6.4 and 6.8) and are becoming the focus of restoration and government–citizen partnerships. Some urban harbours and waterways are being transformed into public spaces for recreation (e.g., the harbours of Hamilton, Collingwood, Montreal, and Quebec City, the Lachine Canal in Montreal, the Toronto–Lake Ontario waterfront, and the drainage basins of rivers in the middle of metropolitan areas, such as the Don and Rouge rivers in Toronto).

The extensive road network provides a flexibility that continues to be instrumental in the expansion of metropolitan areas. Accompanying this urban expansion is the outmigration of people and industries from the central core of the metropolitan centres into the smaller cities and rural areas at their fringes. For the core areas, this means a loss of economic vitality and the appearance of abandoned industrial land, or "brownfield sites." At the outskirts, it means increased stress on the environment and on services and threat to or loss of valued natural areas or agricultural land. It also means increasing conflict between farm use and residential use of the land. Finally, it means long daily commutes, increased traffic density, and high smog levels.

While early growth was largely uncontrolled, leading to "urban sprawl," planning towards more sustainable "polynucleated" metropolitan areas is now being considered. Plans for "walled cities" with private security and governments (of the type becoming more popular in the United States) are being considered for the region around Toronto (H. Regier, Institute for Environmental Studies, University of Toronto, personal communication). Changes in municipal tax structures, strategies for protection of agricultural and valued natural land, better integration of regional governments, and other tools are starting to be applied or are being considered. For the future, the new types of communication corridors, such as fibre optic cables, have the potential to reduce the need for automobile use.

Climate change

Climate change poses potential threats to the sustainability of ecosystems and human society. Responses to such threats include limitation of greenhouse gases, adaptation to changing conditions, and research and monitoring to improve understanding and reduce uncertainties (Mortsch 1995). Chapter 15 discusses global and Canadian efforts to limit greenhouse gases. This section examines questions related to adaptation and work in progress in the basin.

Natural ecosystems can often survive considerable climatic stresses, provided other stresses are not excessive and, for mobile animal species, alternative habitats and migration corridors exist (Regier 1993; Koonce and Hobbs 1994). As described in the section on "Biodiversity and habitat change," habitats and potential migration corridors have been extensively modified in the Great Lakes–St. Lawrence basin, and other stresses abound. The increase and synergy of stresses due to climate change combined with other problems such as toxic substances, competition from exotic species, and eutrophication may be a major threat to ecosystems (e.g., see Regier 1993; Koonce and Hobbs 1994). Long-term salmonid monitoring and long-term ecological monitoring along the boundaries between large ecosystems (such as ecozones) have been proposed as early-warning indicators for climate change (Regier 1993; Canadian Global Change Program 1995).

Water diversions and structures to protect shorelines and regulate water levels are possible societal responses to climate-induced changes in the water balance. As such tactics could compromise the adaptation of aquatic ecosystems, their consequences need to be fully examined before they are implemented (Regier 1993). Moreover, costly interventions such as these and the preservation of specific wetlands or specific fish stocks may be appropriate only for year-to-year fluctuations or for moderate climate changes. Such interventions may be futile, and the investment and benefits lost, if the change is permanent or goes further than expected (Koonce and Hobbs 1994).

For the basin overall, negative and positive economic impacts have tended to offset one another in the scenarios, which is similar to what has been found for other large regions (Mortsch 1995). Society has typically adapted to change through technological advances, increasingly with the help of information technology. In the future, benefits will tend to accrue more to those who can make large investments in new technology. Groups practising a traditional lifestyle, who reside primarily along the shores of the important water bodies, may come under particular stress. Although its potential ecological effects cannot be discounted, climate change may present primarily a social problem — namely, how to provide social equity in the distribution of benefits and losses.

A basin overview

The Great Lakes–St. Lawrence aquatic system is vulnerable to the movement of toxic substances and invading organisms. Persistent toxic chemicals, for example, may migrate with the flow of water from the Great Lakes as far as the Gulf of St. Lawrence; migrating native and exotic species can move the length of the system in both directions. In addition, dams, structures to regulate water levels, and the St. Lawrence Seaway have had considerable impacts on the dynamics of the basin's freshwater ecosystems, changing the frequency of floods and occurrence of wetlands, erecting barriers to migrating fish, as well as providing the means for the invasion of exotic species.

The fish community of the Great Lakes has been dramatically affected by a combination of overfishing, predation from the parasitic Sea Lamprey, destroyed or degraded spawning habitats, blocked migration routes, and eutrophication. Fish

have also been exposed to persistent toxic chemicals, the most drastic effects of which have been observed in birds, reptiles, and mammals that feed on the fish. The community has been almost completely transformed from a predominantly cold-water, bottom-feeding community, dominated by salmonids typical of low-productivity waters, into an open-water community dependent upon the increased supply of nutrients and human management. The dramatic decline in predators allowed the proliferation of nonindigenous Alewife and Rainbow Smelt. To provide game fish for anglers and to control Alewife, most of the Great Lakes have been stocked with large numbers of hatchery-produced, nonindigenous salmon as well as Lake Trout. While there are now self-sustaining populations of Pacific salmon in all the Great Lakes, for Lake Trout this is true only in Lake Superior. Maintenance of these other salmon populations and their requirement for Alewife may make the reestablishment of Lake Trout more difficult. Extensive Sea Lamprey control and stocking are still necessary to maintain populations and satisfy the demands for recreational fishing. Although anglers can now catch large salmon, they are advised to limit or, in some cases, avoid their consumption altogether.

Other dramatic changes may be about to take place in Lake Erie and, to a lesser extent, in Lake Ontario. Recent reductions in phosphate loadings, together with food scavenging by Zebra Mussels, are decreasing overall productivity. The end result may be a lower-productivity lake with a bottom-feeding fish community. An issue already being discussed is whether society prefers a lake with a self-sustaining but less productive aquatic community or a managed lake with lots of stocked fish to catch.

Fish-eating birds, one level higher on the food web, have been affected by toxic contaminants, sending a warning around the world about organochlorine chemicals and what they can do to the offspring of highly exposed species. The levels of toxic chemicals have decreased, and populations of some species have been restored (e.g., Double-crested Cormorants). Even Bald Eagles are nesting again, albeit in low numbers, along the shores of lakes Erie and Michigan. No Bald Eagles nest along Lake Ontario, however; although some observers cite the lack of nesting habitat, there are some indications from contaminant levels in comparable species of fish-eating birds (e.g., Great Black-backed Gulls) that contaminant levels in any Bald Eagles along Lake Ontario could be too high for successful Bald Eagle reproduction (Pettit et al. 1995).

Environmental information on the Great Lakes–St. Lawrence basin is becoming available in more detail and in many new forms. The *Environmental atlas of the St. Lawrence* (St. Lawrence Centre 1992b) contains 23 sheets of maps, illustrations, and text on different aspects of the river (natural, socioeconomic, resource use, stresses, and conservation). In 1993, Web sites on the Internet appeared, making environmental and socioeconomic information for both sides of the border available through linked sites:

- GLIMR (Great Lakes Information Management Resource) is an index of Environment Canada's Great Lakes programs, publications, and databases and a window to other environmental networks. Locator: http://www.cciw.ca/glimr/
- GLIN (Great Lakes Information Network) is a cooperative project of agencies and organizations to provide *one place* for people to find information relating to the binational Great Lakes region. Locator: http://www.great-lakes.net/
- CIESIN (Consortium for International Earth Science Information Network) is an organization dedicated to making information available to a wide range of users. Locator: http://www.ciesin.org/
- GLREIS (Great Lakes Regional Environmental Information System) is a regional directory and data access system being developed by CIESIN, with support from the U.S. Environmental Protection Agency. Locator: http://epaserver.ciesin.org/

In 1995, interactive multimedia information centres were established at the Biosphere Building on St. Helen's Island in Montreal (part of whose information comes from amateur "ecowatchers") and at the EcoDek exhibit at the CN Tower in Toronto.

A few regional considerations

The *Lake Superior basin* is a relatively undeveloped hinterland where there are conflicts between resource use (logging, pulp and paper, and mining) and wilderness conservation. Residents feel strongly that decisions on resource management made outside the region are taken without adequate sensitivity to local interests. Still, there are success stories of locally initiated conservation projects. It is expected that within a few decades, pollution prevention efforts will stop the flow of critical pollutants from within the basin into Lake Superior. Atmospheric transport of pollutants from sources outside the basin will remain the only major input.

The *Lake Erie basin* has been intensively managed for agriculture but is now coming under increasing pressure from urban development. Through sustainable agricultural and forestry practices, soil erosion and nutrient and pesticide loadings have declined without compromising economic security. The remaining unique habitats and species are subject to incremental losses from inappropriate development. Land stewardship and conflict resolution are emerging as tools to settle disputes between conservation and development and to preserve natural areas. Responsible resource use and maintenance of high-integrity natural habitats are coming to be seen as not necessarily mutually exclusive.

In the *Lake Ontario basin*, recovery efforts continue to be challenged by cumulative stresses. Land development upstream in local drainage basins leads to downstream effects on the lake. Many local restoration efforts are under way, but the loss of aquatic species and urbanization may have brought irreversible changes. A consensus is needed to choose among the different conditions still possible for this ecosystem (e.g., the future of a sport fishery in a lake contaminated by massive chemical loadings from the Niagara River).

Along the *St. Lawrence River*, large areas of wetland, forest, and other diverse natural habitats have been replaced by vast expanses of uniform agricultural fields. St. Lawrence Seaway construction and ship traffic have displaced the fisheries, and pollution has limited recreational uses of the river and the fish that may be eaten. However, there has been a change in attitude and approach, towards combining human activities with respect for environmental integrity. This new approach is evidenced by the local Zones of Priority Intervention program, in which residents along the river consult among themselves and with governments to discuss the state of their regions and to determine priorities. Although these consultations can sometimes be confrontational, they constitute an indispensable first step along the road to broader perspectives and joint action. Point sources of pollutants will likely be controlled through government programs such as St. Lawrence Vision 2000. Agricultural runoff and other non-point sources of pollutants pose a more difficult but nevertheless soluble problem. Finally, joint actions will be required to control pollutants arriving in the St. Lawrence by water from the Great Lakes or by air from even greater distances.

The *St. Lawrence estuary*, a transition zone from the St. Lawrence River to the Atlantic Ocean, appears to be still largely unaffected by human activity, with the exception of impacts of toxic contaminants on the Beluga. However, its population has remained relatively stable for the last 20 years and may even be increasing slightly, and the effects of contaminants from upstream on population levels are less evident than might be expected, given the discovery of highly contaminated carcasses. Nevertheless, the complex processes in this aquatic ecosystem make it difficult to detect changes, and monitoring continues in order to receive early-warning signals. The state of the Beluga has been chosen by all agencies involved in the St. Lawrence as an indicator of the success of restoration efforts. The creation of the Saguenay Marine Conservation Area will protect unique habitats, such as the feeding grounds of baleen whales and the enclaves of Arctic and sub-Arctic marine species in the Saguenay Fjord.

Societal responses

In the Great Lakes basin, with its many, often overlapping, public and private institutions, the process by which decisions are made is enormously complex (Francis and Regier 1995). Recently, the Canadian and U.S. governments made a first attempt at a comprehensive evaluation of the state of the Great Lakes, with an emphasis on the aquatic ecosystem (Table 6.17). The situation along the St. Lawrence, with fewer jurisdictions and fewer diverging interests, is not quite as complex.

The foundation of environmental management in the Great Lakes was the Boundary Waters Treaty of 1909, in which the governments of Canada and the United States created the IJC, designated it as a commission of inquiry, and gave it certain powers of adjudication over water resources. The Great Lakes Water Quality Agreement and the Convention on Great Lakes Fisheries built on this foundation. Until the 1980s, the goals set and commitments made were the outcome of negotiations between senior levels of government. The role of the public and other groups was very limited. The first St. Lawrence Action Plan (1988–1993) was similarly an agreement between the governments of Canada and Quebec; public involvement through the Zones of Priority Intervention program was only introduced later during the implementation of the Action Plan. Public involvement in the one other province-wide program, to clean the waters of Quebec (Programme d'assainissement des eaux du Québec, or PAEQ, of 1978), was also limited, as was customary for the time.

Since the mid-1980s, nongovernmental organizations have increasingly become part of the decision-making process. Great Lakes United, a binational nongovernmental coalition, participated in the negotiations for the 1987 amendment of the Great Lakes Water Quality Agreement. This agreement also stipulated public consultations for innovative local Remedial Action Plans and Lakewide Management Plans, leading to the creation of public advisory committees for these initiatives.

Other groups have taken on increasing public roles: the Great Lakes Commission in the United States coordinated the preparation of an ecosystem charter for the Great Lakes–St. Lawrence basin, a document of environmental and social goals signed by many environmental, municipal, Aboriginal, and research organizations (Great Lakes Commission 1994). In Quebec, the St. Lawrence Economic Development Council has prepared a code of ethics for the St. Lawrence River. Other groups have evolved that play an increasing role in managing environment–society interaction in the basin; examples are University-Initiated Networks (Francis and Regier 1995) and various industry groups (Council of Great Lakes Industries). Local groups have also developed initiatives, such as the Lake Superior Binational

Table 6.17

Aggregated indicators for the state of the Great Lakes

Components of the Great Lakes ecosystem	Overall status
Aquatic community	Mixed/improving
Aquatic habitats and wetlands	Poor
Nutrients	Good or restored
Persistent toxics	Mixed/improving
Economy:	
• infrastructure, land use change	Poor
• employment, research and development, population growth, personal income	Mixed/deteriorating
• stewardship, water conservation, energy use	Mixed/improving

Source: Environment Canada and U.S. Environmental Protection Agency (1995a).

Forum. The IJC has played an important role in this "shift of governance," by providing a public forum through its biennial meetings and various other consultation processes and by articulating public concerns in its recommendations.

The change in responsibility has gone farthest in the local programs — the Remedial Action Plans in the Great Lakes and the plans for the restoration of the Zones of Priority Intervention along the St. Lawrence and the Saguenay (see Boxes 6.4 and 6.8). Public involvement in the Remedial Action Plans was established by formal agreement in the 1987-amended Great Lakes Water Quality Agreement. The Zones of Priority Intervention process evolved first parallel to the (1988–1993) St. Lawrence Action Plan but has since become a formal part of the second (1993–1998) Action Plan, St. Lawrence Vision 2000.

Some long-time observers of the Great Lakes region (Francis and Regier 1995) see these groups and networks as constituting a new form of "environmental regime," giving the people of the basin a sense of "bioregional" solidarity. They also see a trend towards a gradual shift in onus in dealing with its environment. In their judgement, the prevailing attitude until the late 1960s was to see the environment as a free good; the onus was on individuals to prove that they had been harmed by the use (or misuse) of the environment by others. This was followed until recently by governments playing the role of guardians of the environment and protectors of society, shielding both from the irresponsible actions of others through regulations, environmental assessments, and extended approval processes. The most recent shift is towards a partial withdrawal of the state (less emphasis on regulations and direct interventions) and a redirection of responsibility to citizens' groups and other sectors of society, including industry associations (e.g., through codes of practice and pollution prevention).

By and large, governments have encouraged this trend, providing financial and logistical support to local groups and initiatives. The public advisory committees for the Remedial Action Plans and the Zones of Priority Intervention receive government funding. As well, the federal government's Action 21 program is specifically based on matching funds for citizen initiatives. Established in 1989 as the Environmental Partners Fund, it approved 159 Great Lakes-based community projects in Ontario. Federal contributions in matching funds of $16.5 million have empowered citizens to take action to rehabilitate or enhance the natural environment. Action 21, which began in 1995, constitutes the new program of financial support that was initiated to assist nonprofit organizations in carrying out projects in four priority areas: biodiversity, conservation of ecosystems, toxic substances, and air issues. Government funding can act as a community catalyst. The program affords opportunities for participants to develop project management skills, establish community linkages, and become adept at fund-raising and forming partnerships. At least two-thirds of the groups funded under the Environmental Partners Fund have continued their activities in another form following the conclusion of the original project. There is optimism that the Action 21 program will have similar results.

In jurisdictions throughout the basin, government support is gradually being withdrawn, and community groups have begun to look for alternative funding sources. These groups have scored some early notable successes. Whether citizen-based initiatives can be effective in the long term in restoring ecosystems remains an open question.

Protecting the natural ecosystems of the Great Lakes–St. Lawrence basin from the stresses outlined in this chapter is a multifaceted and never-ending task. There have been weaknesses and failures, and no doubt there will be more. However, recent decades have also seen important successes, founded on growing public concern for the environment. The application of this concern, together with the considerable analytical skills of all levels of society, gives us optimism that a sustainable Great Lakes–St. Lawrence ecosystem may one day emerge.

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Chapter 7 Atlantic Ecozones

Highlights

Canada's Atlantic ecozones comprise the land-based Atlantic Maritime ecozone and the marine Atlantic and Northwest Atlantic ecozones. The Atlantic Maritime ecozone includes Nova Scotia, New Brunswick, Prince Edward Island, and a portion of Quebec. It represents 2% of Canada's total land and freshwater area and includes 11 200 km of coastline. The Atlantic ecozone encompasses the Grand Banks, the Scotian Shelf off Nova Scotia, and the Gulf of Maine, including the Bay of Fundy; the Northwest Atlantic ecozone includes the Gulf of St. Lawrence, the northern Newfoundland Shelf, the Labrador Shelf, Hudson Strait, and the southern Baffin Island Shelf.

■

Until recently, fishing was an economic mainstay of the Atlantic ecozones. By the late 1980s, however, cod and other Atlantic groundfish stocks were in serious decline. A two-year moratorium on commercial fishing, introduced in 1992, has been extended indefinitely. Unlike groundfish, landings of pelagic and invertebrate species have been stable over the past 10 years. Aquaculture production is growing in value throughout the ecozone.

■

Sewage discharges — containing pathogens, heavy metals, and synthetic organic chemicals — are a major source of pollution in shellfish growing areas. Municipal wastewaters cause approximately 20% of shellfishery closures in the Maritime provinces.

■

Acidification of soil and water continues to be a problem. Acid-generating industrial emissions have been reduced, but many lakes are not recovering as projected. Approximately 30% of the lakes in the ecozone are acidified; about two-thirds of these are acidic as a result of natural causes, and the rest as a result of acidic deposition. Many lakes also have aluminum levels above 100 parts per billion, which is typical of lakes becoming acidified.

■

Ground-level ozone is the most pressing factor affecting Atlantic Canada's air quality. Ozone exposure affects human health, causes agricultural crop losses, and inhibits forest growth.

■

Nearly 1.2 million people in the Atlantic Maritime ecozone rely entirely on groundwater for domestic needs. Ninety-one percent of rural residential water users rely on groundwater, compared with the national figure of 82%.

■

Forests make up 90% of the total land cover and are the predominant ecosystems in the Atlantic Maritime ecozone. Most areas have been harvested several times. Old-growth hardwoods once covered much of the fertile land, but only a few pockets of true old-growth forest remain. In 1993, over 13% of the area harvested was replanted or seeded as plantation. The ecozone is host to two working-scale model forests.

■

Farmland covers 9% of the ecozone. The largest crop is forage for livestock. Other farm products include grains, potatoes and other vegetables, and berries and other fruit. Average farm size increased from 85.8 ha in 1971 to 108.5 ha in 1991. Soil erosion on cultivated lands is a serious problem. Water erosion costs an estimated \$10–12 million per year on potato lands in New Brunswick and \$4–5 million per year in Prince Edward Island.

■

About 65% of the original coastal marshes in Nova Scotia and New Brunswick have been utilized, many of them drained and diked for agricultural uses. The loss of these major wetlands has likely caused significant reductions in wetland-dependent wildlife populations, although such reductions have not been quantified. A large proportion of wetlands are privately owned, hampering efforts of government agencies to influence their management.

■

The Atlantic Maritime ecozone contains 385 protected areas, including six national parks. A total of 1.6% of the ecozone's area is strictly protected. Five wetlands have been designated as significant by the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the Ramsar Convention). The most famous of these is the Bay of Fundy shorebird reserve, which attracts over 2 million shorebirds each fall.

■

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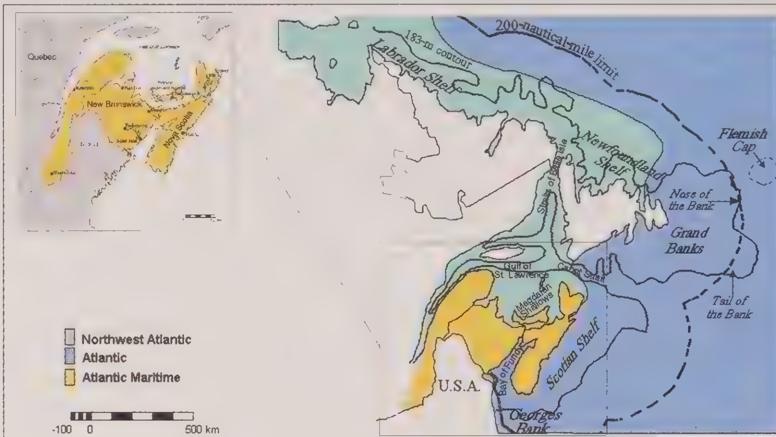
INTRODUCTION — THE ECOLOGICAL RESOURCE BASE

This chapter addresses the major environmental issues affecting three Atlantic ecozones — the terrestrial Atlantic Maritime ecozone and the marine Atlantic and Northwest Atlantic ecozones (Fig. 7.1a). The Atlantic Maritime ecozone covers all of the land areas of New Brunswick, Nova Scotia, and Prince Edward Island. It also covers Îles-de-la-Madeleine and the part of Quebec extending southwest from the Gaspé Peninsula through the Appalachian complex of eastern Quebec to the U.S. border, south of Sherbrooke. The island of Newfoundland is part of the Boreal Shield ecozone (see Chapter 5). The ecozone represents 2% of Canada's total land and freshwater area and includes 11 200 km of coastline. It contains diverse terrestrial and freshwater environments that support a broad variety of wildlife and 2.5 million people (1991; Fig. 7.1b).

The Atlantic ecozone encompasses the Grand Banks, the Scotian Shelf off Nova Scotia, and the Gulf of Maine, including the Bay of Fundy. The Northwest Atlantic ecozone includes the Gulf of St. Lawrence, the northern Newfoundland Shelf, the Labrador Shelf, Hudson Strait, and the southern Baffin Island Shelf. The following sections present an overview of each ecozone, then focus on major environmental issues, including depletion of the fisheries, air and water quality, impacts of forestry and agriculture, and habitat loss.

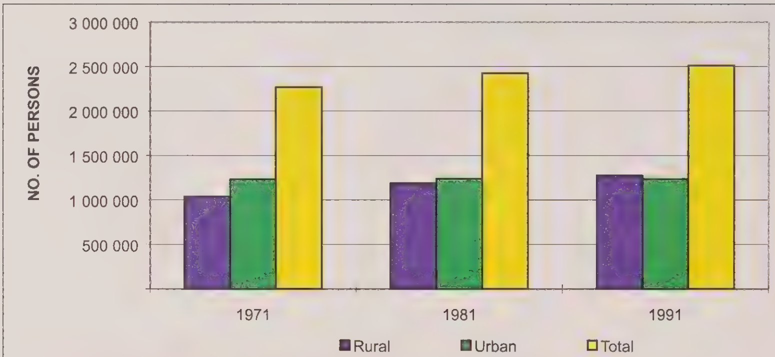
Figure 7.1a
Atlantic terrestrial and marine ecozones



Note: 183-m contour provides a boundary for marine physical features.

Source: State of the Environment Directorate, Environment Canada.

Figure 7.1b
Population trends, 1971–1991



Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada. For further details, see Endnotes.

Atlantic Maritime ecozone

The Atlantic Maritime ecozone is dominated by two principal topographic formations: the northern extension of the Appalachians and the coastal lowlands of the Northumberland Plain. The uplands of New Brunswick and Nova Scotia are composed of granite, gneiss, and other hard crystalline rocks. The soils of the more settled coastal lowlands have developed dominantly on tills derived from glacial erosion of the underlying predominantly sedimentary, and nearby crystalline, rocks. Locally, soils have developed on glaciofluvial, recent fluvial, and marine sediments (e.g., sands and gravels). The proximity of the Atlantic Ocean creates a moderate, cool, and moist maritime climate. Average annual precipitation ranges between 1 000 and 1 425 mm, and mean July temperatures range between 11.2 and 25.6°C.

Human activities have extensively altered the ecozone, beginning with the ditching, diking, and drainage of many salt marshes of the Bay of Fundy by early Acadian settlers. Most native forests have been harvested or burned at least five times, and wildlife species and habitat have been greatly affected (Dilworth 1984). The combination of hunting, parasites, and habitat modification due to logging and fire suppression extirpated the Woodland Caribou from the Maritime provinces by the early 1900s, although a small Gaspé population remains. Intensive fishing has changed the composition of freshwater

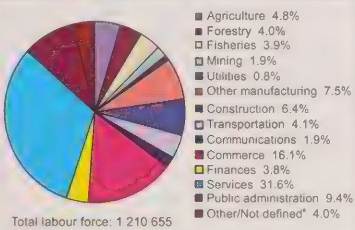
Figure 7.1c
Population change in selected centres, 1971–1991

Selected centres	Population		
	1971	1991	% change
Sherbrooke, Que.	84 570	139 194	65
Rimouski, Que.	28 956	47 818	65
Bathurst, N.B.	16 674	14 409	–14
Fredericton, N.B.	37 684	71 869	91
Saint John, N.B.	106 744	124 981	17
Moncton, N.B.	71 416	106 503	49
Charlottetown, P.E.I.	25 253	57 472	128
Halifax, N.S.	222 637	320 501	44
Sydney, N.S.	91 162	116 100	27

Note: The geographic extent of a Census Metropolitan Area in 1971 may not correspond to that for 1991. For further details, see Endnotes.

Source: Special tabulation prepared by Statistics Canada. For further details, see Endnotes.

Figure 7.1d
Labour force composition, 1991



Note Using the 1970 Standard Industrial Classification, the four primary sectors have been grouped with their respective first-stage resource processing industries. For further details, see Endnotes.

* "Other/Not defined" represents labour force categories that were less than 0.5% of the total labour force as well as responses for which the respondent did not specify the industrial category in which he/she or other household members were employed.

Source Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada.

ecosystems, as has the discharge of agricultural, urban, and industrial wastes in harbours and waterways. The Atlantic or Acadian Whitefish is endangered by overfishing and water pollution.

Economic development and growth are relatively slow in the ecozone. Closures of fish processing plants and mines have been common in the 1990s, leading to severe economic and personal hardship. Between 1981 and 1991, the general labour force increased slightly, from 1 048 370 to 1 210 655 persons. In 1991, agriculture, forestry, fisheries, and mining employed 14.6% of the labour force; the service industries were the largest employer, accounting for 31.6% of the labour force (Fig. 7.1d).

Forests cover 90% of the land area of the ecozone. Mixed coniferous–deciduous forest predominates, covering 50% of the land area. In 1991, the forest sector employed 47 870 people. Although the ecozone's soils, in general, have a number of inherent limitations to agricultural production, there are still significant areas in the Maritimes that have moderately high capabilities — 24% of soils are rated in Classes 2 and 3 of the Canada Land Inventory (CLI) soil suitability for agriculture classification, and an additional 19% are marginally suitable for agriculture (CLI Class 4). These soils support dairy, beef, and poultry production and the growing of fruits and vegetables. In 1991, the agriculture industry employed 57 775 persons (Eaton et al. 1994).

Atlantic and Northwest Atlantic ecozones

Overview

The continental shelf is the dominant geographic feature of the Atlantic and Northwest Atlantic ecozones, extending 150 km off Labrador, 500 km east from Newfoundland, and 200 km off Nova Scotia. It consists of many shallow offshore banks less than 150 m deep separated by basins and channels over 200 m deep.

Surface water temperatures in the Atlantic ecozone have the largest seasonal variations of any part of the Atlantic Ocean. Surface temperatures in the Northwest Atlantic ecozone are higher than those in the Atlantic ecozone, reflecting a transition between polar waters and more southern temperate waters.

In winter, surface temperatures as far south as Sable Island are below 0°C. Low water temperatures occur to depths of 100–150 m as a result of waves and currents created by strong winds. Below this layer are warmer waters that penetrate onto the continental shelf from offshore.

In summer, surface temperatures range from 10 to 24°C in the Atlantic ecozone and vary widely throughout the Northwest Atlantic ecozone. For example, whereas August temperatures range from 2 to 10°C off northern Newfoundland, temperatures on the Magdalen Shallows in the Gulf of St. Lawrence can reach more than 20°C.

During summer, the water column in shelf areas generally consists of three layers: a 30- to 50-m-deep upper layer, warmed by solar heating; a cold intermediate layer extending to depths of 100–200 m; and warm water of offshore origin below the cold intermediate layer.

The dominant oceanographic feature of these ecozones is the southward-flowing Labrador Current, which consists of two branches. The larger branch hugs the continental shelf off Labrador and eventually flows onto the Grand Banks, whereas the smaller branch is found inshore close to the coast. In the Gulf of St. Lawrence, the mean flow of surface waters is generally counterclockwise and is dominated by the Gaspé current (Koutitonsky and Bugden 1990). A wide range in water temperatures results from the contrasting temperatures of the Labrador Current and Gulf Stream.

Tidal elevations typically range from less than 1 m in most of the Gulf of St. Lawrence and off northern Newfoundland to 2–3 m off Labrador. The Bay of Fundy

boasts the highest tidal elevations in the world, reaching 16 m. Those of southern Ungava Bay are the second highest, reaching 12 m.

Surface salinities in both ecozones typically range from 30 to 35 parts per thousand and increase offshore, with the highest salinities in the Gulf Stream waters. The large freshwater discharge from the St. Lawrence River system and rivers along the north shore of Quebec produces low salinities in the southern Gulf. On the Magdalen Shallows, the salinities are generally lower than 30 parts per thousand in summer; in the northeastern Gulf, they reach 32 parts per thousand. Low salinities off northern Nova Scotia reflect outflow from the Gulf of St. Lawrence. High freshwater discharges from Hudson Bay flow through Hudson Strait and are observed in waters of the northern Labrador Shelf. Similarly, freshwater discharges from the Hamilton River system are observed in waters of the southern Labrador Shelf.

The seabirds in the marine ecozones are predominantly migrants from the south Atlantic and European Arctic (Diamond et al. 1993), giving the area global importance for marine biodiversity. Major seabird colonies breed at Baccalieu Island, the Witless Bay Islands, Cape St. Mary's (Newfoundland), and Machias Seal Island (Bay of Fundy). Over 300 000 seabirds breed in Labrador, mainly around Groswater Bay, on Gannet Island, and near the town of Nain. Large colonies are also found on Anticosti Island, Bonaventure Island, and the Magdalen Islands and in the Gulf of St. Lawrence (Box 7.1).

The marine ecozones support large concentrations of shearwaters, gulls, murres, eiders, and cormorants and a wide range of marine mammals, including Harbour Porpoise, dolphins, 22 species of whales, and 6 species of seals. Major fish species include flounder, plaice, Capelin, mackerel, Silver Hake, herring, Haddock, Atlantic Salmon, halibut, cod, redfish, and Turbot (Greenland Halibut). Several Atlantic groundfish stocks have been badly depleted in recent years, resulting in a moratorium on most cod fisheries. Causes of the cod stock decline include overfishing, depletion of food stocks, changing water temperatures, and seal predation.

Box 7.1
Seabird populations in the Gulf of St. Lawrence

The abundance of seabirds along the Gaspé Peninsula in the Gulf of St. Lawrence is world-famous. On Bonaventure Island, 24 000 pairs of Northern Gannets nest "like a white blanket" on the cliffs. The entire Gulf of St. Lawrence seabird population is estimated at 436 000 breeding pairs, with the largest concentration breeding off the eastern Gaspé Peninsula (Lock et al. 1994). In 1989, the most common species were the Black-legged Kittiwake (37.4%), the Common Murre (24.2%), and the Northern Gannet (20.9%) (Chapdelaine and Brousseau 1992).

In the mid-1960s, toxic organochlorines, including polychlorinated biphenyls (PCBs), dieldrin, and dichlorodiphenyltrichloroethane (DDT), were found in the Gulf of St. Lawrence (Chapdelaine et al. 1987). Overwhelming evidence indicates that high concentrations of dichlorodiphenyldichloroethylene (DDE), a breakdown product of DDT, were connected with eggshell thinning and low reproductive success during the late 1960s. The number of Northern Gannet pairs on Bonaventure Island dropped from 20 511 to 16 400 between 1969 and 1976 (Chapdelaine et al. 1987). Other toxins found included dieldrin and PCBs, both connected to embryo mortality, birth defects, including crossed bills, liver abnormalities, tumours, skin lesions, and reduced growth rates (Gilbertson et al. 1976; Peakall 1987; Noble 1990; Noble and Burns 1990).

From 1970 to 1972, initial restrictions were placed on the use of DDT, dieldrin, PCBs, hexachlorobenzene (HCB), hexachlorocyclohexane (HCH), and heptachlor. In 1976, the federal Environmental Contaminants Act *was passed, prohibiting all open uses of PCBs and banning DDT (Noble 1990). Analyses of eggs showed that concentrations of almost all contaminants, particularly DDE, declined between 1968 and 1984 (Noble 1990). In apparent response to the restrictions, the reproductive success, eggshell thickness, and number of birds have improved. But seabirds remain at risk from other sources, including oil spills, gill nets, habitat disturbance, overfishing of food sources, and overhunting (Noble 1990; Eaton et al. 1994).*

Recent climatic trends

Recent winters have brought more cold air and strong northwest winds to the marine ecozones. These have resulted in earlier formation, longer duration, greater areal extent, and later retreat of sea ice (Fig. 7.1e). This has been observed off Labrador, on the Grand Banks off Newfoundland, and in the Gulf of St. Lawrence. Ice forms off northern Labrador in November or December and moves slowly south in great abundance, reaching the Grand Banks in February or March. In the Gulf of St. Lawrence, ice forms in late December and by February generally covers the entire area. Clearing begins in April in the Gulf and in May off Newfoundland. The Labrador coast is generally ice-free in mid-July.

Winter cooling produces cold sea temperatures that persist into the summer and autumn within the cold intermediate layer (see Chapter 10). This layer of water has been colder than normal since 1985 and generally has been deeper off the Newfoundland and Labrador shelves. However, data collected during the last two years suggest that temperatures may be moderating. In 1994 and 1995, the ice retreat occurred at near-normal dates.

In recent years on the Scotian Shelf, water temperatures have varied depending on the depth layer. In the upper layer (top 30–50 m), temperatures have fluctuated above and below normal, with no consistent pattern. Off southwestern Nova Scotia and on the northeastern Scotian Shelf, temperatures in the upper layer were almost as cold as in the early 1960s — the coldest period in the past 50 years. In 1994, an intrusion of deep off-

Figure 7.1e
Characteristics of the Atlantic marine ecozones

Marine ecozone	August surface temperature (°C)	Presence of sea ice	Tidal range (m)
Northwest Atlantic	4–10	Absent during summer; icebergs common in spring and summer	5–9 (Ungava Bay, 12)
Atlantic	10–20 25 in sheltered areas	Winter sea ice off Newfoundland	1–2 (Bay of Fundy, 9–16)

Source: Adapted from Department of Canadian Heritage (1995).

shore waters into the Gulf of Maine reversed the trend, leading to warmer and more saline waters in the upper layer. In the deep waters of the Scotian Shelf and in Cabot Strait, temperatures have generally been higher than usual by 1–2°C. This trend is related to the presence of warmer than normal slope waters — waters separating the Gulf Stream and shelf waters.

HUMAN ACTIVITIES AND ENVIRONMENTAL ISSUES

Fisheries

For 500 years, the seas of Atlantic Canada supported one of the world's richest commercial fisheries. The fishery remained sustainable because only the harvestable surplus was taken. The technology employed — long lines of baited hooks, inshore traps, and small nets — and the relatively low level of total fishing effort limited the catch and resulted in little waste. In the 1950s, however, modern fishing technology and expanding markets for seafood caused dramatic increases in the amount of fish harvested. Powerful new boats and electronic gear allowed crews to harvest fish from offshore aggregations. Modern nets swept up many noncommercial species and undersized young fish along with the target cod and Haddock.

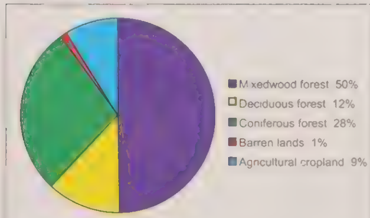
Initially, European trawlers were mainly responsible for the growth of fishing. But Canadians soon adopted the new technologies. In 1977, Canada imposed the 200-nautical-mile (370 km) exclusive economic zone, restricting foreign harvesting to fish in excess of Canada's needs. Yet overfishing continued. In 1993, the Task Force on Incomes and Adjustment in the Atlantic Fishery (also known as the Cashin Task Force) reported:

> What has caused or contributed to this unprecedented and widespread resource collapse? There is no definitive evidence, but there are a number of factors which, in varying degrees and combinations, have had a role in this decline. Among the more important are: overly high Total Allowable Catch (TAC) levels for many stocks, set too high because of overoptimistic scientific projections, inadequate understanding of stock dynamics and inaccurate data on commercial fishing activity; under-reporting of actual catches, which caused harvesting overruns, and misleading data for management and scientific assessments; destructive fishing practices such as highgrading, discarding and dumping of immature fish or nontarget species; foreign overfishing of straddling stocks[1] on the Nose and Tail of the Grand Banks; failure to control expansion of fishing effort, which in part has been in response to the demands of a processing sector plagued by overcapacity, and failure to minimize the possible adverse impact of various fishing gear technologies; and unforeseen and possibly long-lasting ecological changes, including cooling water temperatures since the mid-1980s, changes in water salinity, and shifting predator–prey relationships, particularly among seals, capelin and cod, which have affected adversely the growth, abundance and distribution of various species.

The decline of Northern Cod stocks shows the effects of the above factors, including the impact of new fishing techniques. Between 1850 and 1950, the catch grew from about 200 000 t to about 300 000 t annually. With the introduction of the foreign fleets, the annual catch shot up to a peak of 800 000 t by the late 1960s. This had fallen to about 200 000 t by the mid-1970s. By the end of the 1980s, Northern Cod was in serious decline. By 1989, the fishing fleet had four times the capacity necessary to take the permissible catch. A two-year moratorium on commercial fishing of the Northern Cod stock, introduced in 1992, has been extended indefinitely. Cod usually accounts for half the catch of groundfish. Until recently, almost half the cod catch came from the Northern Cod stock off eastern Newfoundland and Labrador.

In recent years, other northwest Atlantic groundfish have suffered declines similar to those of the Northern Cod. In contrast, landings of several pelagic and invertebrate (shellfish) species have been stable or increasing over the past 10 years. In 1992, groundfish landings accounted for 48% of the total landed weight of the

Figure 7.1f
Land cover distribution



Note: For the definitions of surface cover types, see legend to Figure 10.11, Chapter 10.

Source: National Oceanic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR) imagery. Manitoba Remote Sensing Centre. Manitoba Department of Natural Resources.

1. A straddling stock of fish is a population that travels between exclusive economic zones of two or more countries or between the exclusive zone of one country and the high seas.

Atlantic coast catch, whereas pelagic and anadromous fish accounted for 28%, and shellfish for 24%. Although the shellfish catch was the smallest in volume, it generated more than 60% of the landed value. In comparison, groundfish made up 33% of landed value, whereas other fish represented 7% (Department of Fisheries and Oceans 1994).

Groundfish
Some groundfish stocks in Atlantic Canada are currently the smallest ever recorded, calling into question its spawning capability. Stocks have declined in all of their major habitat areas, including Labrador and the east coast of Newfoundland, in the Gulf of St. Lawrence, and on the Scotian Shelf and Georges Bank off the east coast of Nova Scotia (see Box 11.7, Chapter 11). Declines in catches and biomass have occurred throughout the 1980s and 1990s. Stock decreases are partly due to overfishing (Hutchings and Myers 1994; Myers and Cadigan 1995; Myers et al. 1995). Changes in migration, increases in natural mortality from harsh climatic conditions and changes in water temperature, reductions in food species, and shifting predator–prey relationships have also contributed to the collapses. Studies are ongoing into the ecology of Atlantic groundfish (Box 7.2).

Along the coast of Labrador and the east coast of Newfoundland, cod, the flatfishes, and other species such as grenadiers and redfish have suffered. In 1995, reduced total allowable catches were imposed on Canadian-managed stocks of Turbot.

Cod stocks in the Gulf are at their lowest level on record, and the entire Gulf cod fishery was closed in 1993–1994. The biomass of all redfish (the fishery was closed in 1995), Turbot, Witch Flounder, and White Hake stocks dropped rapidly in the 1990s and continues to decline. The stock of American Plaice has been plagued by high levels of discarding by commercial fishermen and continues at a low level.

Except for a few stocks, groundfish resources on the Scotian Shelf and Georges Bank have declined substantially. The area is dominated by cod, Haddock, and Pollock, but also includes plaice, Yellowtail, Witch and Winter flounder, Atlantic Halibut, redfish, Silver Hake, skate, Monkfish (Goosefish), and White Hake.

Pelagic fish
Atlantic stocks of major pelagic species have undergone an overall decline in recent years, owing to overfishing and harsh environmental conditions, including abnormally low water temperatures. The herring harvest has declined to about 250 000 t annually. Capelin stocks have also declined. Capelin is the principal prey species for cod in the northern Gulf, for seabirds and seals, and for several whale species in the Gulf during the summer. Bluefin Tuna numbers are now very low; even with further harvest reductions, the recovery of stocks will be slow. Swordfish are also under increasing harvest pressure. The exception is mackerel stocks, which are still abundant but could become threatened if market demand increases.

Invertebrates
The harvest of invertebrate species on the Atlantic coast has increased in recent years. Lobster remains the most important invertebrate species, making up more than 25% of total harvested value. After peaking in the early 1990s at over twice the average of previous decades, lobster harvests declined, likely because of environmental factors and, possibly, increased fishing. Shrimp harvests have increased signifi-

Figure 7.1g
Air temperature, degree-days, and precipitation in selected centres

	Air temperature (°C)				Degree-days[a]		Precipitation			
Selected centres	Mean January maximum	Mean January minimum	Mean July maximum	Mean July minimum	Heating (<18°C)	Growing (>5°C)	Mean annual rainfall (mm)	Mean annual snowfall (cm)	Mean total precipitation (mm)	Days with measurable precipitation
Sherbrooke, Que.	–5.6	–17.7	24.7	11.2	5 176	1 621	835	288	1 109	189
Rimouski, Que.	–7.3	–15.4	22.9	12.6	5 248	1 500	609	278	891	149
Bathurst, N.B.	–4.0	–15.4	25.6	12.9	4 794	1 760	845	295	1 131	156
Fredericton, N.B.	–6.0	–15.9	24.7	13.8	5 054	1 669	710	308	1 017	152
Saint John, N.B.	–2.8	–13.6	22.1	11.6	4 817	1 499	1 156	283	1 433	164
Moncton, N.B.	–3.4	–12.2	23.1	13.6	4 748	1 636	869	339	1 201	177
Charlottetown, P.E.I.	–3.7	–13.9	23.1	13.6	4 833	1 649	811	309	1 120	166
Halifax, N.S.	–1.3	–9.6	22.9	12.1	4 636	1 527	1 156	330	1 480	189
Sydney, N.S.	–1.5	–10.3	23.4	13.2	4 422	1 707	1 223	261	1 474	170

Note: Data based on 1961–1990 climatic normals.

[a] A unit of measurement of the deviation of the mean daily air temperature from a predetermined standard (at a particular location). For further details, see definition of degree-days in Glossary.

Source: Environment Canada (1994).

cantly and steadily over the past 10 years, apparently as a result of environmental changes, improvements in fishing technology, and possibly the decline in predators such as cod. Harvesting of Snow Crabs has increased in the southern Gulf in recent years and in 1992 was somewhat above the long-term average. Scallop resources are heavily exploited in most areas, and future yield will depend on maintaining appropriate fishing effort levels.

Anadromous fish

Harvests of Atlantic Salmon — the most commercially significant anadromous species — have decreased steadily in Canada, from 2 680 t in 1980 to 270 t in 1995, owing to reductions in commercial fishing effort and reduced stock abundance. Salmon have also been affected by acid rain. One-third of the available Atlantic Salmon habitat in Nova Scotia has been lost to acidification since 1950. In recent years, measures have been taken to ease the pressure on this declining species: the commercial fisheries have been virtually eliminated, and, in the Maritime provinces and insular Newfoundland, a catch-and-release restriction has been instituted in recreational fisheries on all fish 63 cm in length or longer. Stringent management measures have improved juvenile populations in recent years. However, these increases have not yet improved recruitment, because of a much higher than average natural mortality at sea. The proportion of smolt (young salmonids) surviving to adulthood in the past few years has varied throughout the range and is lowest in the south (i.e., the Bay of Fundy and the Gulf of Maine).

Aquaculture

Aquaculture is a recently developed alternative to the traditional fisheries, which are unable to sustain the increasing world demand for high-quality fish products. New Brunswick has a $120-million salmon farming industry in the Fundy Isles region as a result of highly suitable growing conditions, good infrastructure support (including research, veterinary services, local suppliers of feed and smolts, and an effective growers' association), high flushing rate, and proximity to prime U.S. markets (New Brunswick Department of Fisheries and Aquaculture 1994). In the fall of 1982, production approximated 38 t. Annual production roughly doubled each year from 1984 until 1991, when it stabilized at about 9 000 t. Southern New Brunswick now accounts for approximately 95% of the east coast production of Atlantic Salmon (Stewart 1994). In Nova Scotia, several scallop culture projects are under way, including a major commercial scallop hatchery. Prince Edward Island continues to lead the oyster and mussel aquaculture industry with extensive sales of oysters and mussels worldwide.

The success of aquaculture depends on a variety of factors, in particular the maintenance of unpolluted waters. Pollution from municipal sewage, agricultural runoff, industrial wastewater, fish plant effluent, and other chronic and accidental sources, including aquaculture activities (see Chapter 11), may hamper some operations or cause closures. But these problems are considered manageable over the long term (Eaton et al. 1994).

Ballast water

Plants, animals, and pathogens released into new habitats by discharges of ship ballast water are having dramatic impacts on terrestrial and aquatic ecosystems worldwide (Biodiversity Science Assessment Team 1994). Since 1991, millions of tonnes of ballast water have been discharged in major Atlantic ports. That year alone, the ports of Halifax and Saint John received 2.1 and 2.6 million tonnes of ballast water, respectively, from foreign vessels (D. Gauthier, Marine Environmental Science Division, Department of Fisheries and Oceans, personal communication).

To date, phytoplankton sampling in Atlantic Canada has shown that the frequency of toxic algal blooms in and around Nova Scotia during summer months has tripled over the past 15 years. However, a definitive connection with ballast water releases has yet to be established (Smith and Kerr 1992). In 1981, concerns arose over the introduction of toxic algae from ships bound for the Îles-de-la-Madeleine. Researchers subsequently determined that 60% of ballast waters from ships whose last port of

Box 7.2

Assessing east coast groundfish

The East Coast of North America Strategic Assessment Project (ECNASAP) is a data synthesis and geographic information systems (GIS) mapping project for estuarine, coastal, and marine living resources of the northwest Atlantic. The project is a collaboration among scientists from Canada and the United States. The goal of its offshore case study is to support multispecies management on the continental shelf within an ecosystem context. Key activities include identifying demersal fish (found on or near the bottom) and invertebrate assemblages and analyzing their relationships with habitat, inshore ecosystems, key exploited species, and other major species groups.

A variety of analytical approaches are being investigated for single species and assemblages. The single-species analysis includes tracking 108 demersal species and examining how distributions of Arctic Cod, Ocean Pout, and Butterfish change in five-year time blocks. Preliminary results for these three species indicate significant temporal changes in distribution using GIS.

Future work will assess whether these changes are associated with environmental variation. GIS technology will be used to evaluate changes in the environment and to assess species and assemblage distributions over time. A desktop system will be refined to access, display, and analyze the information. Eventually, researchers hope to define ecosystem management units and key indicators of their status (i.e., species and community attributes).

Source: R.N. O'Boyle, Department of Fisheries and Oceans, personal communication.

call was in Canadian waters contained small concentrations of four potentially toxic dinoflagellate species of the genera *Alexandrium* and *Dinophysis* (Gosselin et al. 1995).

Canada has yet to introduce ballast water exchange regulations. Two voluntary guidelines exist: one for vessels entering the Great Lakes inland waterways through the St. Lawrence Seaway, and one for those bound for the Îles-de-la-Madeleine in the Gulf of St. Lawrence. Scientists have noted that a national action plan is required to address the risks to Canada's aquatic habitats and resources, leading possibly to policies, regulations, and an integrated research program regarding ship-transported ballast water (Gauthier and Steel 1996).

Sustainability of marine commercial fisheries

Canadian fisheries resources are managed to ensure a sustained economic and social value consistent with biological conservation. Thus, for each species harvested, estimates of yield are set on the basis of biological advice and estimated economic and social benefits. Achieving these objectives is a formidable task. Global demand for fish protein is increasing, and communities in Atlantic Canada depend on the fishing industry for employment and revenue (Eaton et al. 1994). The northwest Atlantic fishery faces threats from both environmental and human sources. Figure 11.24 (Chapter 11) shows northwest Atlantic catches from 1960 to 1992.

But awareness of the vulnerability of marine resources and the need for their protection is growing. In 1994, to strengthen conservation of stocks outside the 200-nautical-mile limit, the federal government amended the *Coastal Fisheries Protection Act*, authorizing Canada to take enforcement measures to protect and conserve straddling stocks in areas regulated by the Northwest Atlantic Fisheries Organization (NAFO). The goal was to ensure sustainable management of these high-seas fisheries pending the implementation of permanent international measures giving Canada the power to protect fish stocks that migrate outside Canadian waters.

In March 1995, Canada and the European Union engaged in a dispute over Turbot fishing and other conservation issues in the northwest Atlantic. In April 1995, an agreement was struck that enhanced conservation and enforcement measures for straddling stocks in the NAFO Regulatory Area (NRA). This included a new sharing agreement for the Turbot stock and a requirement for all Canadian and European Union vessels fishing in the NRA to record catches. Canada is also a signatory to a new United Nations agreement that gives the international community the means to end overfishing of straddling and highly migratory stocks on the high seas.

Air systems — air quality

Air pollution influencing the Atlantic region comes from local sources, the United States, and central Canada. Toxic contaminants from various industrial processes and pesticide residues are brought by prevailing winds and weather systems. Although air quality problems are most serious in urban and industrialized centres, even remote rural areas undergo exposure to ground-level ozone and acidic deposition, two of the main problems the area faces. The potential impacts, observed trends, and management responses for the major contaminants in the ecozone are being monitored on an ongoing basis. Background information on the atmosphere is contained in Chapter 10.

Ground-level ozone

Ground-level ozone, a pollutant of concern in urban smog, is the most pressing factor affecting Atlantic Canada's air quality. Ground-level ozone is formed when pollutants — nitrogen oxides (NOx) and volatile organic compounds (VOCs) — imported from the eastern seaboard of the United States hundreds of kilometres away react with sunlight. This photochemical activity predominates in the summer (CCME 1990), when more than half of the population is routinely exposed to unacceptably high ozone concentrations. The human health effects of ozone exposure include coughing, increased aging of lung tissue and decreased lung capacity, and increased risks to asthmatics, children, the elderly, and people working or exercising outdoors (Thomson 1992; see also Table 10.2, Chapter 10).

Ozone causes agricultural crop losses for ozone-sensitive species such as potatoes, tobacco, and tomatoes, and it can cause noticeable leaf damage in other species. Forest trees and other vegetation may be injured or their growth inhibited (Spavold-Tims 1985; Thomson 1992; New Brunswick Department of the Environment 1994). Levels of ground-level ozone are highest in Saint John, which recorded over 90% of the 114 episodes between 1977 and 1988 when acceptable limits were exceeded in the ecozone (Environment Canada 1988).

Nitrogen oxides and VOCs are among a variety of toxic air pollutants known as hazardous air pollutants. Hazardous air pollutants originate primarily from petroleum processing and use, automobile exhaust emissions, pesticides, industrial operations such as smelting, plating, and paper production, and the combustion of fossil fuels and wood.

These pollutants are being controlled by various measures: eliminating their generation in industrial and other processes, adding emission control systems, improving combustion, requiring additional emission controls on automobiles, and reducing the content of toxic compounds in fuels and other consumer products. In October 1995, the Canadian Council of Ministers of the Environment (CCME) endorsed proposals concerning cleaner vehicles and fuels, including limits on sulphur in diesel fuel and benzene (a VOC) in gasoline. As well, Canada and the United States are considering expanding the scope of the 1991 Air Quality Agreement, which now focuses on acid rain, to include transboundary ground-level ozone (Government of Canada 1996).

Acidic deposition

Acidic deposition, or acid rain, as it is more popularly known, is caused by emissions of sulphur dioxide (SO_2) and nitrogen oxides (see Chapter 10). These

pollutants react with moisture in the atmosphere to form sulphuric acid and nitric acid, respectively. Once released into the atmosphere, acidic pollutants may be transported great distances by the prevailing winds and weather systems before being deposited in wet form, as precipitation or fog, or in dry form, as acidic gas or dust.

Much of the Atlantic Maritime ecozone is sensitive to acidic deposition, as it lacks the alkaline soils and bedrock necessary to buffer or neutralize the acidic pollutants. Acidic deposition contributes to declining tree growth rates as well as increased death rates in trees. For example, instances of dieback and deterioration have been noted in White Birch in southeastern New Brunswick as a result of acid fog. High levels of acidic deposition result in the acidification of acid-sensitive lakes and rivers and cause metals to leach from surrounding soils into the water and groundwater systems. High acidity and elevated levels of metals can seriously impair the ability of water bodies to support aquatic life, resulting in a decline in indigenous species, including fish, insects, and plants. Approximately 30% of the lakes in this ecozone are acidified; 30% of these lakes have become acidified as a result of acidic deposition, and the remainder are acidic as a result of natural causes (Howell and Brooksbank 1987).

Although Canadian sulphur dioxide emissions have declined over the past decade, Atlantic Maritime ecozone lakes with low alkalinity are not recovering as projected. These lakes also have aluminum levels above 100 parts per billion (ppb), which is typical of lakes that are becoming acidified.

A target of 20 kg of sulphate in precipitation falling on 1 ha in a year (20 kg/ha per year) was established as an interim objective of eastern Canada's efforts to reduce acidic deposition — a level that, in the early 1980s, was thought to be adequate to protect aquatic ecosystems that were moderately sensitive to acidification (RMCC 1990). However, scientists are suggesting that for many acid-sensitive ecosystems, this target may be too high, as 20 kg/ha per year exceeds the buffering capacity of many lakes in eastern Canada. A study by Duchesne and Ouimet (1996) has concluded that this target may also be too high for certain sensitive forest ecosystems in the Quebec portion of the ecozone. Certain areas in this ecozone continue to receive elevated levels of sulphate deposition. For example, wet sulphate deposition ranges from 12.7 to 15.7 kg/ha per year in New Brunswick and is highest in the most acid-sensitive region in the southern part of the province. Over 80% of New Brunswick's wet sulphate deposition originates outside the province, primarily from the United States (New Brunswick Department of the Environment 1995). Nitrate deposition is also a contributor to the acidification process and averages 10–12 kg/ha per year in New Brunswick.

Air and environmental sustainability
Efforts to improve air quality are under way throughout the Atlantic Maritime ecozone (Table 7.1), and ambient air levels of most pollutants are within acceptable ranges and improving. On average, annual sulphur dioxide emissions have declined gradually since the early 1980s (Fig. 10.5, Chapter 10). In 1985, the federal government and the governments of the seven easternmost provinces agreed to reduce emissions east of the Saskatchewan border to 2.3 million tonnes a year by 1994. This target was surpassed when 1994 emissions in eastern Canada totalled 1.7 million tonnes. Highly sensitive aquatic ecosystems are not protected by this target.

The primary regional source of sulphur dioxide is fossil fuel combustion in power generating stations. In 1994, New Brunswick Power, which accounts for about 60% of provincial emissions, emitted 90 000 t of sulphur dioxide, well below its limit of 123 000 t (New Brunswick Department of the Environment 1993). This was achieved largely by the addition of scrubbers at the Belledune and Dalhousie generating stations. In Nova Scotia, the Point Aconi circulating fluidized bed facility constitutes a major component of Nova Scotia's acid reduction program. It is capable of removing approximately 90% of sulphur dioxide.

Bilaterally, the 1991 Canada–U.S. Air Quality Agreement committed Canada to capping national sulphur dioxide emissions at 3.2 million tonnes by the year 2000 and eastern Canadian sulphur dioxide emissions at 2.3 million tonnes between 1994 and 2000. The United States also committed to reducing sulphur dioxide emissions by 40% from 1980 levels. Despite these successes, acid rain will continue to be a focus for action in the post-2000 era.

Freshwater systems — water quantity and quality

The Atlantic Maritime ecozone generally has an abundance of fresh water, although local supply problems do occur (Fig. 10.14, Chapter 10). Surface waters and groundwaters are used for drinking, agriculture, power generation, and a variety of other industrial activities. Fresh water is an integral part of the landscape and has significant recreational value. The quality of the ecozone's water, however, has come under increasing threats in recent years from contaminants emanating from municipal, agricultural, and industrial sources. Groundwater, a primary source of drinking water, has suffered considerable contamination, with corresponding risks to human health (Table 10.12, Chapter 10).

Water use
The Maritime provinces have more than 25 000 lakes, ponds, and rivers, with 13 113 in Nova Scotia, 11 335 in New Brunswick, and 1 105 in Prince Edward Island. Many lakes are small, less than 5 ha, especially in New Brunswick and Prince Edward Island (Eaton et al. 1994). The ecozone has one of the highest runoff and groundwater baseflow ratios (ratio of precipitation entering surface water and groundwater sources to total precipitation) in the country — almost 83% of the precipitation appears in rivers and streams. The geology, slope of the terrain, high annual rainfall, and low rates of transpiration and evaporation all contribute to this high ratio. Peak flows usually occur during the April and May snowmelt, with flows gener-

Table 7.1
Towards maintaining and improving air quality

Province	Recommended actions	Initiatives
New Brunswick	• Classify all major airsheds over New Brunswick. • Examine the feasibility and implications of a 20% reduction of 1988 carbon dioxide emission levels by the year 2005. • Develop incentives to ensure that all chlorofluorocarbons (CFCs) in New Brunswick are recycled by 1995, and develop legislation, in harmony with the federal government, to phase out CFCs and other major ozone depleters or restrict them to closed-cycle uses by 2010.	• There are five Air Resource Management Areas (ARMAs), roughly defined on the basis of location of emission sources, environmental sensitivity, population, and information gained by environmental monitoring. These are Saint John–Fundy, Madawaska, Restigouche–Chaleur, Nepisiguit, and Miramichi. The precise boundaries of each area will be determined as the planning process proceeds. Other ARMAs could be established at a future time in the interest of maintaining pristine or relatively unpolluted conditions.
Nova Scotia	• Encourage the adoption of new technology for reducing carbon dioxide and sulphur dioxide emissions from coal combustion. • Develop methods for reducing greenhouse gas and other undesirable emissions through a system of offsetting credits, tradeable emission permits, or other similar means. • Develop power rate structures that encourage conservation. • Review new motor vehicle registration and tax schedules to encourage fuel efficiency. • Establish industry performance standards for residential wood-burning devices.	• Reduced acid-precipitation-producing emissions to 169 000 t in 1994. This additional reduction beyond the existing 189 000 t commitment was attained by the implementation of efficiency and conservation measures. • Federal–provincial negotiations on the NOx/VOCs Reduction Program, the Global Warming/Greenhouse Gases Reduction Program, and the Ozone Depleting Substances Reduction Program.
Prince Edward Island	• Participate in national and international air quality management plans, and implement the Comprehensive Air Quality Framework for Canada. • Amend the Canada–Prince Edward Island Reduction Agreement on Sulphur Dioxide as proposed.	• Development of reforestation programs for both urban and rural areas by the Forestry Division. • Endorsement of the CCME NOx/VOCs Management Plan and steps to reduce emissions. • Development of bilateral agreements on specific pollutants such as VOCs, carbon dioxide, and NOx. • Participation in the development of the National Action Program on Climate Change, released in February 1995.
Quebec	• Reduce greenhouse gas emissions to 1990 levels by the year 2000. • Reduce acid rain. • Improve energy efficiency by 15% by the year 2001. • Eliminate or reduce toxic emissions attributable to transportation.	• Quebec action plan for meeting its commitments under the United Nations Framework Convention on Climate Change. • Cooperation agreement between Quebec and New York State. • Quebec energy efficiency strategy (1992). • Environmental policy of the Ministère des Transports.

Source: Nova Scotia Round Table on Environment and Economy (1992); Premier's Round Table on Environment and Economy (1993); P.E.I. Department of Environmental Resources (1994, 1995); Ministère de l'Environnement et de la Faune du Québec (1996).

ally lowest during late summer, when rainfall is less and soil moisture reserves have been depleted.

Groundwater is a critical resource in the ecozone — 91% of rural residential water users rely on groundwater, compared with the national figure of 82%. In total, nearly 1.2 million people rely on groundwater for domestic needs, and municipal water use in the ecozone is increasing. In 1981, an estimated 307 million cubic metres of water — the equivalent of 123 000 Olympic-sized swimming pools — were drawn from municipal supplies in the ecozone. Without conservation efforts and improved techniques for using water, this volume is projected to increase to 435 million cubic metres per year by 2011 (Tate and Scharf 1985). Groundwater also supplies 90% of all water used for agriculture (Eaton et al. 1994). The major commercial users of groundwater include manufacturing, mining, agriculture, and thermoelectric plants. Thermoelectric plants are the single largest user of water in the ecozone, accounting for more than 60% of water withdrawal; however, water is returned unpolluted, except for added heat.

Water quality

Preserving freshwater ecosystems and the quality and availability of the ecozone's fresh water is a major environmental, social, and economic challenge. Contaminants from several sources influence the quality of both surface water and groundwater (see Chapter 10). Pollutants in surface water and groundwater come from localized point sources or dispersed non-point sources. Point sources include industrial effluent, acid rock drainage, municipal and stormwater sewers, and septic tanks and tile drains. Non-point sources include runoff from field applications of fertilizers and pesticides, sedimentation from agricultural and forestry operations, long-range transport from distant sources, including groundwater interflow (flow between underground water sources), and contaminants in urban surface runoff. Some watersheds are also contaminated by naturally occurring substances.

Municipal wastewater, a source of contamination for surface water and groundwater, originates from homes, businesses and industrial workplaces, and stormwater runoff. Wastewater and solid residuals can carry various chemicals, bacteria, and pathogens harmful to humans. Urban stormwater can contain petroleum hydrocarbons, road salt, and other contaminants. In most large urban centres, stormwater is discharged directly into a surface water body without treatment. The discharge of municipal water is responsible for approximately 20% of shellfishery closures (Menon 1988). Health effects have also been documented. Data for the Quebec portion of the ecozone, for example, show that over 850 persons contracted gastroenteritis and diarrhea from drinking water between 1989 and 1993. In 75% of the 28 reported outbreaks, the drinking water consumed had not been treated (Bolduc 1996).

Agricultural practices, including use of fertilizers and pesticides, are a major source of non-point source pollution (Pearse et al. 1985). A toxic chemical survey of municipal drinking water sources in Atlantic Canada found elevated nitrate concentrations (above 1 part per million [ppm] but less than 10 ppm) in groundwater sources in areas of high agricultural use (O'Neill et al. 1992). A 1990 study of wells in rural Kings County, Nova Scotia, showed that nitrate levels in 12.4% of the wells surveyed exceeded the 10 mg/L (10 ppm) level recommended in the Guidelines for Canadian Drinking Water Quality. The study also found detectable levels of pesticides in 41% of the wells, with 96% of the occurrences at less than 1 ppb (Nova Scotia Department of the Environment et al. 1990). Water contaminants from natural and human sources are addressed by various provincial agencies, depending on the source.

In areas of intensive potato production, surface water quality is adversely affected by agricultural non-point source pollution. Monitoring of surface water quality in the Wilmot watershed in Prince Edward Island (Dehaan 1994) and the Black Brook watershed in New Brunswick (Chow et al. 1995) indicates particularly high concentrations of suspended solids, some exceeding 20 000 ppm, following heavy rainfall and runoff. Nitrate concentrations are also well above background levels, ranging from 2 to 9 ppm, but sometimes peaking above the 10 ppm level recommended in the Guidelines for Canadian Drinking Water Quality. Pollution from agricultural sources affects the quality of Quebec rivers, in particular the Chaudière and Etchemin rivers (Bureau de la Statistique du Québec 1995).

Urban stormwater runoff is second only to agricultural runoff as a non-point source of pollution (Pearse et al. 1985). As the land surface is developed for urban uses, large areas of the watershed are covered with pavement, buildings, and other impervious structures. Because storage and infiltration of water are greatly reduced, surface runoff during rainstorms or thaws is relatively rapid in the urban watershed (Lazaro 1979). In this situation, rainwater quickly washes both organic and inorganic materials into storm sewers and directly into the aquatic or marine environment. Among the organic pollutants, polycyclic aromatic hydrocarbons occur in the greatest quantities by weight (Marsalek 1986). Toxic substances found in stormwater runoff include heavy metals, hydrocarbons, and some chlorinated organics. Heavy metal concentrations in runoff typically exceed the safe threshold limits for freshwater biota; localized sources include galvanized culverts (zinc), metal finishing plants, and vehicle and industrial combustion.

In many areas cleared of mature forest cover, sediment pollution of lakes and streams is a serious water quality problem. Sediment pollution not only causes water to be murky and aesthetically unpleasant but also reduces the light available to underwater plants and reduces fish populations by contaminating food supplies and habitats. Some sediment action is a natural consequence of stream erosion, but agricultural development typically increases erosion rates by four to nine times (Montgomery 1989). However, such erosion is minimal, as only 9% of the ecozone has agricultural land cover.

Sustainability of freshwater ecosystems
Public recognition of the importance of fresh water to society's well-being and scientific understanding of regional freshwater resources are growing. Throughout the ecozone, community groups have started community-based water quality monitoring projects to encourage awareness and stewardship of local water resources. Several water conservation programs are already under way. The municipal Water/Energy Conservation Project in Middleton, Nova Scotia, is studying the effectiveness of water conservation methods. The City of Moncton is considering modifying its reservoir spillway to retain more water in dry seasons.

Each of the provinces has identified the central water issues and the actions required to make water quality sustainable (Table 7.2). Initiatives such as the Ministers' Task Force on Clean Water in Nova Scotia and the new *Nova Scotia Environment Act* aim to encourage community-based stewardship, watershed management, and water resource classification.

Forest ecosystems

The forest industry exerts an overwhelming impact on the terrestrial areas of the Atlantic Maritime ecozone. Forests have been harvested in the ecozone for longer than anywhere else in Canada. These forests consist of a distinctive blend of coniferous (softwood) and deciduous (hardwood) species. Old-growth hardwoods once covered much of the fertile land, but only a few pockets of true old-growth forest remain. Secondary and successional growth are more common.

The forests support much of the ecozone's wildlife. Mammals include White-tailed Deer, Moose, Black Bear, Snowshoe Hare, porcupine, beaver, marten, Eastern Coyote, and Northern Flying Squirrel. The lakes and shaded waterways support trout, salmon, herons, loons, and waterfowl, whereas nearby tall trees are nesting sites for Ospreys and eagles. Unfortunately, wildlife species that prefer mixedwoods, hardwoods, and a diversity of age structure lose habitat when natural forest is replaced by softwood plantations. In 1993, over 13% of the area harvested was replanted or seeded as plantation (Canadian Council of Forest Ministers 1995). Table 11.4 (Chapter 11) shows the percentage of timber-productive forest classified as mature or overmature, by province.

The socioeconomic importance of forests
The forests are an important resource for all ecozone inhabitants. In Quebec, as in most other parts of Canada, most forestland is controlled by the Crown. In the Maritimes, however, a large proportion of forestland is privately owned, totalling 90% in Prince Edward Island, 75% in Nova Scotia, and 50% in New Brunswick. These lands contain some of the ecozone's most productive and easily accessible forest and are indispensable to local forest industries.

In some rural areas of New Brunswick, Nova Scotia, and Quebec, forestry may be the sole source of employment and the major reason for a community's existence. The pulp and paper industry is the largest consumer of wood, using 65% of the annual harvest. Approximately 24% of harvested wood is sawn into lumber (Brown 1990). In addition, the ecozone's forests are commercially harvested for biomass fuel — wood chips used in commercial boilers and fuelwood used in domestic heating. Other commercial forest products include Christmas trees and poles for construction and fences.

Impacts of forestry
The total area planted in New Brunswick, Nova Scotia, and Prince Edward Island declined from 34 167 ha in 1990 to 19 529 ha in 1993 (the last year for which data are available), a reduction of 42% (Canadian Council of Forest Ministers 1995). The practice of establishing plantations is declining for financial and biological reasons. This region's forests, when cut, regenerate vigorously. Harvesting operations today are designed to more carefully protect advanced natural regeneration in the understorey, to establish the future crop. As well, many 30- to 40-year-old plantations are beginning to become available for harvest today. Companies had originally planned to clear-cut these plantations when they were first established. In fact, these same companies are commercially thinning rather than clear-cutting them, with excellent results. Yields are high enough to make the operations economically viable. The remaining forest has numerous openings to the forest floor created, which is allowing new flora and fauna that need this particular forest condition to become established. In New Brunswick, for example, companies are required to always have a certain amount of mature conifer forest habitat available for some 50 species of birds and animals to inhabit. These thinned plantations are meeting the criteria at an earlier age than originally anticipated and will provide forest managers with more options for meeting the diverse needs reflected in integrated resource management.

As well, much experimentation is being undertaken with fill planting in naturally regenerating areas to improve stocking, which by default brings more diverse species into these sites than the former single-species plantations. Mixed-species plantations are also being tested for biological and financial viability. On balance, the question of negative effects on biodiversity from single-species plantations in the ecozone is a matter of scale. Block sizes from cuts are much smaller today, creating smaller openings and smaller plantations when these are established. Forest managers and planners are creating a much different forest for the future in 1996 than 10 years ago, with less plantation in the traditional style (D. MacFarlane and G. Savage, Canadian Forest Service, Natural Resources Canada, personal communication).

The advent of more mechanized forestry practices has increased the potential to seriously harm land and water resources. Forestry roads make the forests more accessible for hunting, recreational use, and development. Uncontrolled and careless use of the forest ecosystem for recreation and hunting, especially the use of all-terrain vehicles, can cause serious damage to the forest environment and to sensitive habitats. Forest degradation can also have negative impacts on tourism. In Quebec, for example, where nature is being promoted as a theme in tourism

marketing, sound forest management is considered important to attract foreign visitors.

Insects, diseases, and fire

Repeated infestations of insects and diseases, severe fires, and windthrow can lead to the death of stands of trees and thus initiate secondary succession, or they can alter the forest composition by reducing a particular species. In recent years, the area harvested has greatly exceeded areas of reduced growth or foregone volume of timber (Fig. 7.2) — in contrast to the situation in the Boreal Shield ecozone, for example (see Chapters 5 and 11).

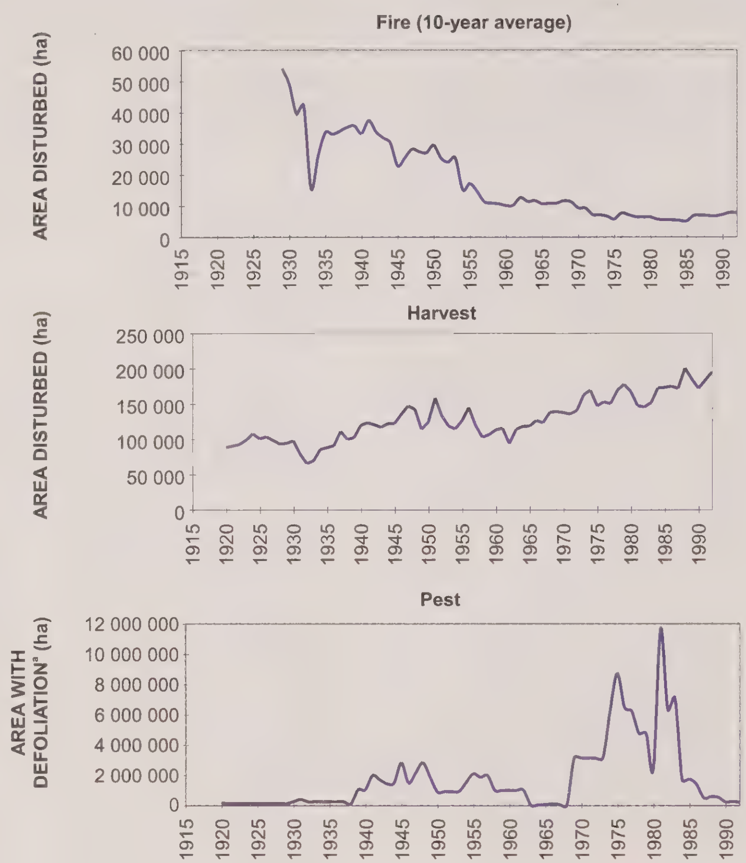
In natural forests, indigenous insects (Spruce Budworm, Hemlock Looper) show cyclical outbreaks, whereas others have static populations. A combination of predators, parasites, and climate keeps these pests in check. Forest plantations, in which the checks and balances of a natural forest have been disturbed, are more vulnerable. Native and introduced pests can cause severe problems in plantations, as has happened with the Spruce Budworm and the Seedling Debarking Weevil (Cox et al. 1989). The Spruce Budworm, a native of eastern spruce–fir forests, is considered the most destructive forest pest in Canada today. The most

Table 7.2
Towards sustainability of water quality

Province	Issues/needs	Recommended actions	Initiatives
New Brunswick	• Nutrient pollution. • Salt pollution. • Sedimentation. • Contamination of groundwater.	• Provincial water management strategy. • Water sale and export policy. • Potable Water Regulation (effective 1 January 1994) under the *Clean Water Act* sets microbiologic, inorganic, and organic parameters. • Ecosystems approach by drainage basin.	• Provincial land use policies covering - floodplains; - water supply protection; and - watershed management. • Watercourse Setback Designation. • Stream classification.
Nova Scotia	• Protection of aquatic ecosystems. • Safe, reliable water supplies. • Effluent discharge. • Water demand. • Sedimentation. • Nutrient pollution. • Pesticides.	• Policies to integrate water and land use planning. • *Water Resource Act*. • Water quality standards. • Watershed management plans. • Water databases. • Stewardship (community-based). • Water export policy.	• Sewage treatment plant funding. • Clean Annapolis River Project. • Dartmouth Lakes Advisory Board. • Reduction of pesticide use by the Department of Transport. • Sydney Tar Ponds cleanup. • Ministers' Task Force on Clean Water. • New *Environment Act*.
Prince Edward Island	• Shared management responsibilities. • Polluter pays. • Integrate land and water uses. • Education.	• Reduce agricultural impacts. • Develop safe drinking water regulations. • Promote water research and conservation. • Improve sewer servicing.	• Watercourse alterations. • Petroleum storage tank removal. • Buffer areas between subdivisions and watercourses or wetlands. • Water quality assessment and monitoring. • Watersheds Improvement/Recreational Fisheries program. • Environmental Emergency Response Team (home heating fuel tank spills).
Quebec	• Effluent discharge. • Nutrient pollution. • Groundwater protection. • Protection of aquatic ecosystems. • Drinking water quality.	• Government subsidy of an average of 85% of the cost of the construction of wastewater treatment plants in certain municipalities. • Various measures to ensure drinking water quality, including the protection of underground and surface water intakes. • $191-million federal–provincial agreement to protect the St. Lawrence ecosystem and its seven main tributaries. • Integrated water management project operating on a watershed-by-watershed basis. • Guidance on agricultural practices with a view to reducing adverse impacts. • Development of standards on contaminated water and wastewater discharges.	• Municipal water treatment program of the Ministère des Affaires municipales, since 1994 (continuation of the Programme d'assainissement des eaux du Québec of the Ministère de l'Environnement et de la Faune [MEF]). • MEF's Drinking Water Regulation, policies and programs of regional county. • St. Lawrence Vision 2000 (Quebec and the federal government). • Creation in 1994 by MEF of the Chaudière River Basin Committee • Amendments to the Regulation Respecting Pesticides and development of the pesticides management code. • Amendments to the Regulation Respecting Wastewater Disposal Systems for Isolated Dwellings.

Source: Nova Scotia Round Table on Environment and Economy (1992); Premier's Round Table on Environment and Economy (1993); P.E.I. Department of Environmental Resources (1994, 1995); Ministère de l'Environnement et de la Faune du Québec (1996).

Figure 7.2
Forest disturbances in the Atlantic Maritime ecozone



[a] Area with moderate to severe defoliation by insects.

Source: ESSA Technologies Ltd. (1993); Canadian Forest Service, Natural Resources Canada, Ottawa.

recent outbreak of the Spruce Budworm, beginning in the late 1960s, destroyed or severely damaged many of the large areas of natural mature, even-aged fir and spruce stands, as well as plantations.

Fenitrothion, once the most widely used chemical insecticide in New Brunswick forests, is being phased out by 1998. Large-scale aerial spraying has been restricted since the beginning of 1995, as a result of public opinion and following studies by Environment Canada's Atlantic-based Pesticides Issues Team that determined that large-scale spraying of fenitrothion was environmentally undesirable. The practice will cease completely after December 1998 (Government of Canada 1995), although use of fenitrothion will be permitted for small-scale treatment of woodlands and forests.

The biological insecticide Bt (*Bacillus thuringiensis*) is replacing chemical insecticides in operations where it can be effective. In Quebec, for example, Bt was used in preference to chemical insecticides from 1987 until 1993, when the use of all forest insecticides was stopped. The Bt bacteria can kill larvae of all lepidoptera (butterflies and moths). Spruce Budworm and Jack Pine Budworm larvae, in particular, typically emerge for spring feeding ahead of other lepidoptera. To be harmed by Bt, nontargeted lepidoptera would have to be at the same stage of development — and feeding in the canopy of the same forest stands — at the time of application as the budworms and other pest species, such as the Hemlock Looper. Integrated pest management for forests is being studied; it incorporates silvicultural and biological control methods such as pheromones, nematodes, and fungi, as well as insect disease bacteria such as Bt. The Canadian Forest Service, in collaboration with industry, is working on a new biochemical called "Mimic" (tebufenozide), which is effective against the Spruce Budworm and may be approved for use in 1996 (Natural Resources Canada 1995).

During the 1930s, 1940s, and 1950s, birch dieback altered forest composition by killing several species. The cause was never fully understood, but the condition reduced birch throughout much of New Brunswick and Nova Scotia (Freedman 1989). Recurring, early, and usually severe foliage browning and premature leaf fall have affected White Birch trees along the Bay of Fundy. There are now strong indications that coastal acid fog and ground-level ozone may be contributing factors (Cox et al. 1989; Magasi et al. 1994).

Fire is a natural part of forest ecology. Before human influence, fires were less frequent but often affected larger areas. Since the early years of settlement and active land clearance, many forest fires have had human causes. Modern fire suppression efforts have succeeded in reducing the area of forest destroyed by fire each year.

Windthrow or blowdown can cause considerable damage. On 7 November 1994, in

north-central New Brunswick, 2.8 million cubic metres of Crown forestland were lost (the approximate equivalent to one year's cut) as the result of a severe windstorm.

Sustainability of forests
Each of the four provinces in the ecozone is addressing forest sustainability (Table 7.3). Beginning in 1995, clear-cutting is being replaced in Quebec by alternative harvesting techniques to protect regenerating forests and soils. Quebec is developing the concept of an "inhabited forest" — a new approach to managing forests close to populated areas. This type of community forestry promotes the development of all forest resources and shares management responsibilities among local residents and communities. In New Brunswick, forest uses other than wood production have been given a higher priority in recent management decisions (see Box 7.3).

There are two working-scale model forests in the ecozone, the Fundy Model Forest in southern New Brunswick (419 266 ha) and the Lower St. Lawrence Model Forest in Quebec (112 634 ha). They reflect a variety of values, such as wildlife, biodiversity, watersheds, recreation, fisheries, and wood supply. The objectives are to accelerate the implementation of sustainable forest development, particularly with regard to integrated resource management; to develop and apply innovative concepts and techniques in the management of forests; and to test the best sustainable forestry practices available. The sites are managed by partnerships involving industry, environmental and conservation groups, Aboriginal communities, education groups, private landowners, outdoor recreation clubs, and governments.

Incentive programs to promote good forestry practices on private lands have been an important part of Federal–Provincial Forest Resource Development Agreements (FPFRDA). Through these programs, silviculture, including reforestation, and proper road construction are becoming more common on private woodlots. However, in 1995, the federal government put off any future FPFRDA. In New Brunswick and Nova Scotia, provincial government funding will offset federal contributions, but the withdrawal of federal funding will likely have significant repercussions for program development. Throughout the ecozone, however, a better understanding of forest ecology and the cumulative impacts of forest management is being pursued as part of implementing sustainable forest development.

Agroecosystems
Agriculture is another significant land-based industry of the ecozone. Farmland, which occupies about 9% of the land area (Fig. 7.1f), is concentrated in a few areas in the Saint John River Valley, Maritime Lowlands, Appalachians, Prince Edward Island, and Annapolis–Minas Lowlands ecoregions (Kienholz 1984; Eaton et al. 1994). In many areas, agricultural production is hampered by inherent soil factors such as low fertility, undesirable subsoil structure or low permeability, excessive stoniness, excessive moisture, and unfavourable topography (Nowland 1975). However, 46% and 28% of Prince Edward Island's soils are in CLI Classes 2 and 3, respectively, whereas about 18% of soils in both Nova Scotia and New Brunswick are in CLI Class 2. The largest crop is forage for livestock. Agricultural land is also used for grains, potatoes and other vegetables, fruit orchards, and berries.

Agricultural production has in some cases affected soil and water quality. In the past, where the land was suitable for agriculture, traditional, small-scale agriculture had little negative effect on soil or water. Between 1971 and 1991, however, while the total number of farms decreased substantially — from 34 175 to 20 568 — average farm size increased from 85.8 to 108.5 ha (Statistics Canada 1992). The remaining farms have tended to use more intensive production methods, requiring large machinery and substantial inputs of agrochemicals.

Degradation of soil structure
Many of the agricultural soils in the ecozone have weak inherent subsoil structure, consisting of naturally compacted subsoils and hardpans (hardened soil layers with greatly reduced porosity). Such soils are common along the Northumberland shore and in the central part of Nova Scotia, as well as in most of New Brunswick (Topp et al. 1995). Structural degradation of the soil by compaction is a serious problem in the potato- and other vegetable-growing areas of New Brunswick, second only to water erosion in impact. The use of heavy machinery on moist, fine-textured soils during the wet conditions of early spring and late fall accelerates structural degradation. The risk is highest in soils under row

Box 7.3
New Brunswick's Forest Land Habitat Management Program

In 1992, the Government of New Brunswick introduced changes to its forest management planning process, broadening its focus from ensuring a sustainable timber supply to including objectives for wildlife habitat. As part of the new process, the province undertook a habitat supply analysis to identify forest-dependent wildlife species and their specific habitat requirements. Forecasts pointed to a shortage of mature coniferous forests in 20–30 years that would affect the 25 bird species and 4 mammal species identified as dependent on this habitat.

Under the Forest Land Habitat Management Program, industry management plans now include objectives for maintaining specific amounts of wildlife habitat. The amount of habitat is determined by identifying the needs of an "indicator" species. The American Marten, which is particularly dependent on mature coniferous forests, was chosen as an indicator species for mature habitat. The provincial analysis identified the minimum viable population level for martens at 250 adults. This population would require a total of at least 50 000 ha of suitable habitat, in patches of no less than 500 ha, connected by travel corridors. Preserving habitat for the marten should benefit other species that rely on similar habitat.

Source: Natural Resources Canada (1995).

Table 7.3
Towards sustainable forestry

Province	Issues/needs	Recommended actions	Initiatives
New Brunswick	• Multiple use of forested lands. • Use of pesticides and effect on water quality. • Diminishing wildlife populations in forests.	• Establish working demonstration forests that practise sustainable forestry, integrated pest management, multispecies plantation, and multiple use over an entire watershed. • Develop an economic incentive plan to double the present value of finished wood products by 2010. • Reforestation programs for urban and rural areas. • Develop a plan to recycle wood fibre, postconsumer waste.	• Provincial Federation of Woodlot Owners released a code of practice in 1994 as part of stringent land use guidelines and practices. • Fundy Model Forest initiative for sustainable forest management practices.
Nova Scotia	• Enhance the viability of forest-based manufacturing industries by diversifying industry and increasing valued-added products based on a sustainable and diverse forest ecosystem. • Enhance fish and wildlife habitats, water quality, recreational opportunities, and associated values.	• Prepare a long-term forest management plan. • Develop a natural resource accounting system that reflects the full economic and environmental costs of forest use. • Develop a strategy to reduce the impact of off-road vehicles on wildlife, wildlife habitat, and the forest environment. • Encourage pulp and paper plants to switch to chlorine-free pulp bleaching.	• A forest accord, signed in December 1994, provides a broad-based commitment to continue implementing the National Forest Strategy. Goals include refining forest inventory information, reviewing harvesting and silvicultural activities, and establishing demonstration forests for sustainable forest management. • Government and industry are cooperating to assess the impacts of various forest management operations and to develop techniques that can be used to enhance wildlife habitat.
Prince Edward Island	• Poor harvesting practices. • Disease and insect problems. • Steady decline of tree quality.		• Stewardship and Sustainability: A Renewed Conservation Strategy for Prince Edward Island. • 22 million seedlings planted in 1994 to reduce soil erosion. • Breeding bird surveys documenting responses of native bird species to exotic tree species, such as Norway Spruce and exotic larches.
Quebec	• Promote the management and development of forests on the basis of sustainable use of ecosystems. • Involve industry and other forest sectors in the achievement of objectives respecting the sustainable use of biological diversity.	• Government measures aimed at maintaining sustained yield and conserving the biophysical components and biological diversity of forests. • Sharing responsibilities for management and action with local and regional communities with a view to achieving integrated resource management. • Forestry and ecological inventories, forestry accounting, and remote sensing programs. • Adopt a preventive approach to forest management and development. • Promote a forest development approach that: - respects the natural dynamics of forests; - promotes natural forest regeneration; - takes account of the specific features of forest sites; and - promotes the maintenance of the genetic stock in the forest environment through appropriate silvicultural practices.	• Forest Protection Strategy (1994) and Regulation Respecting Standards of Forest Management for Forests in the Public Domain (1988) adopted by the Ministère des Ressources naturelles (MRN), and introduction of forest allocation and management contracts. • Concept of inhabited forest proposed by the MRN. • Programs of MRN in cooperation with the Ministère de l'Environnement et de la Faune, the Laurentian Forestry Centre, and Laval University and with the forest industry regarding forest research. • Identify development scenarios for fragile forest ecosystems. • Develop experimental protocols for measuring the effects of the principal silvicultural treatments and incorporate means for taking account of biological diversity. • Prohibit all stand conversion activities. • Promote natural and artificial regeneration. • Maintain an appropriate proportion of hardwoods in mixed stands. • Promote reforestation with a variety of species. • Encourage the forest industry to maintain and increase research funding to develop high-yield manufacturing processes (finished products containing less wood fibre). • Continue to provide financial incentives to paper and wood recycling industries. • Develop effluent disposal technologies. • Promote the use of underutilized tree species in industrial processing.

Source: Nova Scotia Round Table on Environment and Economy (1992); Premier's Round Table on Environment and Economy (1993); P.E.I. Department of Environmental Resources (1994, 1995); Ministère de l'Environnement et de la Faune du Québec (1996).

crops, moderate under spring cereals and fruit trees, and low under winter cereals, forages, and pasture.

The loss of soil organic matter from farmlands in the ecozone has reached 15–30% since cultivation began (Gregorich et al. 1995). Only about 20% of potato fields in Prince Edward Island have organic matter levels above 3%, a level indicative of good soil quality for potato production. Better crop rotations (i.e., potato–grain–forage) are being promoted to increase soil organic matter. Benchmark studies in New Brunswick show that erosion controls such as grassed waterways and terraces minimize soil erosion and, consequently, loss of soil organic matter (Wang et al. 1995).

Soil erosion by water

About 80% of cultivated land in New Brunswick, 87% in Nova Scotia, and 81% in Prince Edward Island are at high to severe inherent risk of erosion by water. The problem is particularly serious in the potato fields of Prince Edward Island and New Brunswick (Wall et al. 1995). Potato fields are generally left bare after harvest and over winter, with no cover crop. In Prince Edward Island, there has been a significant effort to mulch these fields with hay or straw. Also, between 1981 and 1991, about 1 500 ha under potato production in Prince Edward Island and about 3 000 ha in New Brunswick were protected by variable-grade terraces, grassed waterways, or strip cropping.

The inherent potential for erosion by water is high owing to the slope of land, fragile soil structure, and wet maritime climate. These conditions, combined with agricultural practices, result in a cumulative erosion loss. In New Brunswick, land cultivated up and down slope is eroding at an average annual rate of 17–32 t/ha (Saini and Grant 1980; de Jong et al. 1986; Chow et al. 1990). This rate of loss is serious, as it has taken centuries to form the 40–50 cm of topsoil on the ecozone's farmlands. Water erosion costs an estimated \$10–12 million per year on potato lands in New Brunswick and \$4–5 million per year in Prince Edward Island (Fox and Coote 1986). Differential rates of soil displacement due to tillage and water erosion have created within-field variability that affects crop production, reducing yields by up to 27% in some areas (Cao et al. 1994).

Agrochemical use in the ecozone

Soil contamination from the intensive use of chemical pesticides and fertilizers is a potential issue in the ecozone. Although pesticide contamination of agricultural soil is not considered a serious problem in Canada as a whole, occasional elevated levels can occur locally. A more serious concern is contamination by heavy metals, which enter agricultural soils mainly through atmospheric deposition and the application of fertilizers and other soil amendments (Webber and Singh 1995). Traditionally, agriculture relied on cultural practices and nonchemical means to control pests and maintain fertility. However, to sustain modern economic production levels, today's farmers use more intensive cropping systems, more efficient machinery, and more pesticides and fertilizers than previous generations (Eaton et al. 1994). In the Beauce–Appalaches region of Quebec, soil degradation is caused by monoculture of corn, other cereals, and potatoes — the last requiring high levels of fertilizers (Tabi et al. 1990a, 1990b; Arbour 1994).

The area of land treated with insecticides and fungicides increased between 1986 and 1991 in both Prince Edward Island and Nova Scotia (Statistics Canada 1992). Increasingly, insect pests are developing a resistance to chemicals: in 1955, 25 species of insects were known to be resistant to pesticides; by 1980, there were 450 (Eidt et al. 1989). More than half the pesticides sold in the ecozone are fungicides, used mainly on potato and fruit crops.

In Quebec, the agricultural component of St. Lawrence Vision 2000 (Environment Canada 1996a) is conducting agri-environmental diagnoses on the Boyer, Chaudière, and Yamaska river basins using a 1995 survey of farmers by the Bureau de la Statistique du Québec (1995). A good indicator of the pressure exerted through agriculture on environmental quality is the intensity of the use of agrochemical inputs, such as pesticides and mineral fertilizers. Despite a substantial decline in cultivated areas in recent decades, the average quantity of pesticides used increased from 0.73 to 1.33 kg active matter per cultivated hectare between 1978 and 1992, or a rise of 82% over 14 years. The use of mineral fertilizers has also increased; annual consumption has reportedly increased from 125 000 in the 1950s to 500 000 t today. It is therefore not surprising to find these contaminants in the waterways crisscrossing the agricultural regions of Quebec, as well as in the underground water table (Environment Canada 1996a).

Agrochemicals and groundwater

Most agrochemicals enter the groundwater in areas with intensive production of annual row crops, because these are heavily fertilized to ensure high yields. Prince Edward Island has the highest percentage (71%) of farms using fertilizer (Statistics Canada 1992). Average nitrate–nitrogen concentrations in the groundwater in potato-growing areas range from 4 to 10 mg/L, but levels above the drinking water standard (10 mg/L) have been detected in several areas. The amount of non-point source nitrate leaching into groundwater has not risen in recent years, indicating that the potential for contamination of drinking water is not increasing. Production of grass for hay and haylage, which is the Maritimes' most common agricultural activity, contributes only low to moderate amounts of nitrate to groundwater (Reynolds et al. 1995).

Sustainability of agriculture

Agricultural sustainability depends greatly on the sustainability of soil. Research on soil quality and degradation has been undertaken by the federal government and the four provinces of the ecozone (Nowland and Halstead 1986). A national Agricultural Soil Quality Monitoring Benchmark Site Network has been set up to monitor changes in soil quality over time (Agriculture Canada 1992), whereas agri-food agreements between the federal and provincial governments promote research into environmental problems. A five-year investigation by Environment Canada and Agriculture and Agri-Food Canada will try to determine the environmental behaviour of pesticides and

nitrates in the climatic, topographic, and soil conditions of the Maritime provinces.

Farmers in the ecozone receive technical and financial assistance to reduce soil degradation and improve storage facilities for manure and pesticides (Agriculture Canada 1990). Agricultural practices that conserve soil, water, and wildlife habitat are encouraged, including conservation tillage, crop rotation, cover cropping, well-planned drainage systems, and maintenance of hedgerows (Eaton et al. 1994). The main issues, recommended actions, and initiatives for agricultural sustainability have been identified for each province in the ecozone (Table 7.4).

Habitat loss

Loss of habitat is the greatest threat to the wildlife of the Atlantic Maritime ecozone. Approximately 60 mammal, 300 bird, 13 reptile, 14 amphibian, and 55 fish species live in Atlantic Canada (Eaton et al. 1994). Many of these species have become endangered or threatened (Table 7.5). The major threats to wildlife habitat include forest conversion and drainage of wetlands for agriculture. The potential for oil spills from ocean-going tankers, overland transport, and storage tanks is also a constant threat to wildlife.

Forest conversion

Forestry practices have had the greatest impact on terrestrial wildlife habitat in the ecozone. Clear-cutting, the most common method of forest harvesting, is recommended as the economical choice for logging and for producing even-aged stands. However, unlike natural disturbances, clearcuts eliminate all standing trees and leave little debris, causing changes in the microclimate and possible changes in the composition of the regenerating species community. For example, clearcuts create more edge habitat, which is more suitable for certain species. Forest harvesting, fires, and severe Spruce Budworm infestations have reduced the mature forest to the extent that in 1991, only 30% of the forest in the Maritimes was classed as mature, compared with a national total of 46%.

Loss of wetlands

Since the early 1700s, freshwater and marine wetlands in the ecozone have been drained and diked for agricultural uses. About 65% of the original coastal marshes in Nova Scotia and New Brunswick have been utilized (Eaton et al. 1994). Wetlands are often perceived as having little economic value in their natural state and are vulnerable to land development activities such as draining and infilling. The loss of these major wetlands has likely caused significant reductions in wetland-dependent wildlife populations, although such reductions have not been quantified.

Wetlands provide vital habitat for many species because of water cover, water depth, and associated vegetation (Fig. 10.12 and Box 10.1, Chapter 10). Many wetland plants, like the endangered Furbish's Lousewort along the Saint John River, have limited distributions and cannot easily extend their habitats or adapt to new areas. Wetlands cover 8% of the land surface of New Brunswick, 3% of Nova Scotia, and 1% of Prince Edward Island (Twolan-Strutt 1995).

Sustainability of wildlife habitat

The federal and provincial governments are instituting measures to reduce the degradation of wildlife habitat. For example, timber management guidelines have been implemented to limit the maximum size of clearcuts on Crown land everywhere except Prince Edward Island. Some private woodland owners, including large companies, are following the Crown land guidelines, resulting in clearcuts that are less extensive and buffered on all sides by trees. In March 1995, Prince Edward Island released its provincial wildlife policy; in September 1995, New Brunswick released a new wildlife policy. Nova Scotia has developed a wildlife policy and strategy, but it has yet to be adopted (Wildlife Advisory Council 1993). The chief issues, recommended actions, and initiatives concerning natural areas and wildlife have been identified in each province (Table 7.6).

Initiatives have been undertaken to replace and develop aquatic habitat. For example, the Department of Fisheries and Oceans (1986) has a strict policy of no net loss of fish habitat. If a fish habitat is reduced by a road, bridge, or other development, the area affected must be replaced by a new stream or a diversion of the existing stream. The impacts of wharves, causeways, and infilling projects on the coastal marine ecosystem are largely undocumented. However, the environmental effects of the Northumberland Strait Bridge project will be monitored (Box 7.4).

Each provincial government in the ecozone is setting aside protected areas (Table 10.9, Chapter 10). Currently, there are 385 protected sites, including 6 national parks, representing 8.4% of the terrestrial ecozone (0.18% of Canada's total land mass). A total of 1.6% of the ecozone is strictly protected (Environment Canada 1995). Each provincial government has committed to completing a system of protected areas. The New Brunswick Protected Natural Areas Coalition envisions a network by 2000 that will include each of the 35 natural regions or ecodistricts. Nova Scotia's strategy proposes 31 sites totalling 2 870 km². Prince Edward Island aims to protect 7% of the island by 2000 and some marine areas by 2010. Quebec has 1 288 km² of protected areas in the ecozone and has committed to completing a network of representative areas by 2000. Several areas have been identified as environmentally significant, including five wetlands designated by the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the Ramsar Convention) (see Chapter 14). The most famous of these wetlands is the Bay of Fundy shorebird reserve, which attracts and feeds over 2 million shorebirds each fall (Environment Canada et al. 1994).

Coastal ecosystems

Efforts to manage coastal zones in the ecozone provide an apt case study of the challenges involved in achieving environmental, social, and economic sustainability. The coastal zone includes both the land and the adjacent sea, with all the associated biota and resources. The coastal environment is used extensively for housing, commercial fishing, recreation, tourism,

Table 7.4
Towards sustainable agriculture

Province	Issues/needs	Recommended actions	Initiatives
New Brunswick	• Heavy dependence on energy. • Cultivation practices that deplete organic matter and soil fertility. • Soil compaction and erosion. • Depletion of natural soil nutrients. • Security of agricultural land tenure. • Reasonable return on investment for farmers.	• Environmental monitoring and audits: assess impacts on land, water, air, wildlife. • Environmental assessment of new technologies. • Incentives to protect best farmland. • Soil and water conservation practices. • Incentives to farmers to retire marginal lands and protect wetlands.	• Agriculture and Agri-Food Canada research centre in Fredericton and the Eastern Soil and Water Conservation Centre. • Provincial agriculture extension efforts.
Nova Scotia	• Soil fertility and a sustainable income for farmers. • Sustainable yields. • Negative impacts of agricultural activities on water quality. • Consumption of locally grown products vs. imports. • Waste disposal.	• Develop provincial land use policies and encourage municipalities to protect lands with good agricultural potential. • Develop policies and programs for sustainable farm management practices and technology. • Analyze pesticide use and criteria for synthetic pesticide use by farmers related to rights of adjacent residents. • Develop strategy to reduce impacts of off-road vehicles on agricultural land.	• Integrated Pest Management Program. • Federal–provincial million-dollar agreement to help farmers adopt soil and water conservation methods. • Provincial land evaluation program to inventory farm resources and recommend most appropriate land uses. • Provincial and Federation of Agriculture sustainable development initiatives on pesticide safety and disposal; provincial and growers' initiatives on environmental protection. • Provincial agriculture extension efforts.
Prince Edward Island	• Soil erosion.	• Reduce soil erosion through control measures, reduction of highway construction impacts, construction site control plans, and research. • Road construction and repair to minimize soil erosion and siltation of streams. • Strict erosion control measures for forest road construction projects; stringently enforced buffer strips where herbicides are used; restrictions on use of heavy equipment near streams.	• Improved potato tillage practices. • Land Management Assistance Program (Agriculture and Agri-Food Canada): projects include winter cover crops, no-till seeding, strip cropping, diversion terraces, shelterbelts, and improved livestock watering systems along watercourses. • Pilot environmental farm planning project, completed under the Green Plan. • Soil and water research conducted at the Agriculture and Agri-Food Canada research centre in Charlottetown. • Provincial agriculture extension efforts. • Coastal Area Policy, 1992, which includes provisions to reduce soil erosion. • 22 million tree seedlings planted in 1994
Quebec	• Ensure the sustainable use of agricultural resources • Ensure the preservation of the genetic diversity of domesticated species.	• Training program and good practice guides regarding the use of pesticides in agriculture. • Balance between environmental, economic, and social concerns in the agricultural sector. • Maintain the integrity of agricultural land. • Cooperate with sector stakeholders and farmers to provide them with assistance or increase their awareness of the conservation use of biological diversity. • Protect natural habitats from adverse effects associated with agricultural activities. • Make sites available in rural environments for the maintenance of natural populations of species. • Identify existing agricultural genetic resources in Quebec and evaluate their status and method of protection and management. • Protect habitats that are critical to the maintenance of native species that are of interest to the agri-food sector. • Control exotic organisms that are a menace for domesticated species	• Resource conservation plan by clubs-conseils supported by the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ) • Manure Management Improvement Assistance Program, initiated by the Ministère de l'Environnement et de la Faune (MEF) in 1988 and transferred to MAPAQ in 1993. • Creation of surplus manure management by MAPAQ in association with agricultural sector stakeholders. • 1987 *Pesticides Act* and MEF programs with MAPAQ, the Ministère de l'Education, and the Ministère de la Santé et des Services Sociaux • Sustainable development policy adopted by MAPAQ in 1995 • Pursue the implementation of the *Act to Preserve Agricultural Land*. • Measures taken to conserve resources and reduce the use of chemical inputs. • Measures aimed at 3 800 farms, making it possible to solve approximately 60% of the problems of non-point source pollutant loadings to rivers and streams. • Measures aimed at resolving problems of surplus manure in the drainage networks of the Chaudière, Yamaska, and Assomption rivers • Protect the resource and regulate commercial harvesting of wild mushrooms • Maintain the application of acts and programs aimed at controlling pathogens of domesticated species

Source: Nova Scotia Round Table on Environment and Economy (1992); Premier's Round Table on Environment and Economy (1993); P.E.I. Department of Environmental Resources (1994, 1995); Ministère de l'Environnement et de la Faune du Québec (1996).

and commercial shipping and is a critical habitat for wildlife. Coastal areas are increasingly exposed to chemical and physical stresses from industrial and municipal development, resource extraction, and aquaculture.

An integrated approach to managing the coastal zone emerged during the mid-1970s, primarily because of the need to preserve valuable coastal resources under increasing pressures. Much of the population of the ecozone lives near the coast. Coastal waters have consequently become the disposal sites for sewage, urban runoff, industrial discharges, and effluent from pulp and paper mills. As a result, many contaminants are found in coastal sediments and biota (Gray and Eaton 1994), and there have been impacts on the area's biodiversity. Coastal ecosystems can also be affected by global stresses, most notably increased ultraviolet radiation resulting from stratospheric ozone depletion, changes in sea levels, and the potential of global warming.

Biodiversity

Threats to the biodiversity of the marine environment arise from habitat modification and destruction, excessive exploitation, loss of genetic diversity, modification of species relationships, and introduction of new species (Cognetti and Curini-Galleti 1993). Acidic precipitation has caused the loss of genetically distinct salmon populations from 13 rivers and the depletion of populations in another 18 rivers in southwestern Nova Scotia (Watt 1986). The St. Lawrence Beluga population, 525 animals in 1992, is important to the regional economy because of its value for tourism. This Beluga population is classified as endangered by the Committee on the Status of Endangered Wildlife in Canada.

The intertidal zone is one of the most biologically diverse parts of the coastal region. It is species-rich, with a large number of algae, lichen, and vascular plants providing food and habitat for a wide variety of animals (Thomas 1983). Rockweed, a brown seaweed common in the Bay of Fundy, is a typical intertidal plant. It provides critical nursery habitat for Common Eiders — especially in southwestern New Brunswick — and for fish, including herring. Loose rockweeds decompose and provide a major food source for marine biota. Rockweed has been harvested commercially for a number of years in Nova Scotia, and New Brunswick has investigated potential commercial harvesting along its Fundy coast. Because rockweed is so ecologically important, harvesting must be sustainable.

Until recently, wetlands were considered wasteland and not a separate unique habitat. The federal government began subsidizing the diking of marshes and wetlands for agriculture in the 1940s. Approximately 65% of maritime coastal marshes remain diked today (Eaton et al. 1994). However, federal subsidization programs for diking were discontinued in the 1940s. Salt marshes are now recognized as one of the most productive ecosystems on Earth. These areas are

Table 7.5

Endangered and threatened species, subspecies, and populations in the Atlantic ecozones, 1995

	Status and geographic location			
Species group	Endangered	Province	Threatened	Province
Mammals	Cougar (eastern population) Whale, Right Whale, White (St. Lawrence and Ungava Bay populations)	NB, NS, QC QC NB, NS, PEI, QC	Caribou, Woodland (Gaspé population) Porpoise, Harbour (Northwest Atlantic population)	QC NB, NS, PEI, QC
Birds	Duck, Harlequin (eastern population) Falcon, Anatum Peregrine Plover, Piping Shrike, Loggerhead (eastern population)	NB, NS, QC NB, NS, PEI, QC NB, NS, PEI, QC QC	Tern, Roseate	NS, QC
Reptiles	Turtle, Leatherback	NB, NS, PEI, QC	Turtle, Blanding's (Nova Scotia population)	NS
Fish	Whitefish, Acadian	NS		
Plants	Coreopsis, Pink Lousewort, Furbish's Mountain Avens, Eastern Sundew, Thread-leaved Water-pennywort	NS NB NS NS NS	Aster, Anticosti Gentian, Plymouth Golden Crest Pepperbush, Sweet Redroot	NB, QC NS NS NS NS

Note: No amphibians are listed as endangered or threatened in the Atlantic ecozones.

Source: Committee on the Status of Endangered Wildlife in Canada (1995); ecozone information compiled by M.J. Kerr-Upal based upon the COSEWIC information in combination with range/distribution maps from COSEWIC status reports and various published wildlife authorities.

Table 7.6
Towards sustainability of natural areas and wildlife

Province	Issues/needs	Recommended actions	Initiatives
New Brunswick	• Effects of forest harvesting on biodiversity: spraying of herbicides and pesticides, single-species planting, clear-cutting, disposal of wood waste and by-products. • Effects on biodiversity of industrial and service sector waste and emissions. • Threats to migratory and endangered species. • Coastal management and development policies.	• Prepare an action plan for natural reserves to adequately represent the major ecoregions of New Brunswick • Develop incentives for landowners and corporations to provide wildlife habitat. • Promote the incorporation by government of wildlife habitat considerations in the management of sectors such as forestry, mining, and agriculture	• Identifying provincial objectives in wildlife management through the development of an extensive habitat inventory • Clearcuts limited to 100 ha in 1993 • Purchase of wetlands from landowners under the Eastern Habitat Joint Venture of the North American Waterfowl Management Plan
Nova Scotia	• Protection of natural heritage and biological diversity • Representation of habitats and regions • Intrinsic value of unique and representative natural areas	• Enact legislation to protect endangered species. • Develop a system to permit and encourage the conservation of species and habitats on private lands • Complete a network of protected areas adequately representing each of the province's theme regions by the year 2000. • Develop a strategy to reduce the impact of off-road vehicles on wildlife, wildlife habitat, and the forest environment	• A system plan of representative areas on private and Crown lands, based on provincial natural regions, completed in 1993 • Revision of the *Natural History of Nova Scotia* document, which defines 9 regions and 64 subregions • Eastern Habitat Joint Venture program • Recovery plans for threatened species • Proclamation of Ramsar sites for shorebirds • Coastal 2000
Prince Edward Island	• Preservation of species and habitat diversity. • Effects of pesticides and dams on wildlife species. • Protection of wintering habitat for migratory birds.	• Increase and improve habitat on Crown and private lands. • Encourage watershed improvement projects. • Implement the Significant Environment Areas Plan.	• Conservation of over 1 000 ha of privately owned wetlands in 1994 • Designation of both Crown and private lands as natural areas The goal is to protect 70 of 94 sites by the year 2000 To date, about 3 500 have been designated under the *Natural Areas Protection Act.* • Over 50 community groups are receiving technical and financial assistance for habitat restoration projects In 1994, these projects cleaned up 264 km of streams and surveyed 184 km of streams to plan for future work • The Western Hemisphere Shorebird Reserve Network and the Neotropical Wetlands Program help protect wintering habitats of migratory birds • Clearcuts limited to 50 ha in 1994
Quebec	• Increase the understanding and enhance the management of biological diversity using an ecosystem-based approach. • Identify and acquire a better understanding of the components of biological diversity of forest ecosystems (genetic diversity, species diversity, ecosystem diversity, and ecological processes). • Increase the ecological knowledge required to establish the network of protected areas and the preservation of vulnerable or threatened components of natural biological diversity. • Establish and maintain an integrated, representative network of protected areas. • Conserve species and ecosystems outside protected areas. • Meet the demand subject to the maintenance and sustainable use of wildlife resources.	• Aim to use a territorial frame of reference for increasing knowledge of ecosystems and their management. • Pursue the development of integrated resource management. • Develop techniques for monitoring biological diversity. • Protect threatened or vulnerable species and their habitat. • Expand knowledge of the components of biological diversity of Quebec forests (public and private). • Inventory data as a function of biological diversity. • Increase the knowledge of ecosystems and species. • Pursue the consolidation and development of Quebec's park network. • Pursue the consolidation and development of the network of ecological reserves • Develop regional parks. • Ensure the protection of wildlife habitats • Develop technical and financial incentives to promote the conservation of natural sites by the private sector. • Adopt and take appropriate measures to minimize impacts of the use of sensitive environments or areas adjacent to protected areas. • Manage populations of harvested wildlife species in such a way as to ensure that the diversity of all species that form part of the ecosystem is not threatened	• Harmonize the use of the different territorial frames of reference • Use or develop geomatics applications for optimizing management efforts • Assess integrated resource management projects currently under way. • Promote the implementation of integrated management on other public and private lands • Develop biological indicators for nonharvested species • Develop indices of biological integrity in aquatic environments • Improve systems for monitoring - harvested wildlife species, - priority species and ecosystems of the St Lawrence, and - forest ecosystems at different scales • Prepare and implement recovery plans for threatened or vulnerable species • Encourage local stakeholders to enter into agreements to bring their activities (agricultural, mining, etc) in line with the objectives pursued in protected areas • Acquire ecological data in forest environments • Analyze existing ecological and forest inventory data as a function of biological diversity • Develop projects to more effectively assess the economic, social, and cultural values of biological diversity • Consolidate and diversify the activities of the Centre de données sur le patrimoine natural du Québec • Pursue the implementation of the provincial parks action plan (1992–1997) • Implement a five-year program (1995–2000) that will be focused on the representativeness of ecological resources in keeping with an ecological framework of reference for Quebec, the protection of wetlands and the protection of the habitat of threatened or vulnerable species of flora • Develop the network of wildlife sanctuaries • Develop management plans for specific wildlife species - large wildlife (4 species) - fur-bearing animals (4 species), and - fish (7 species)

Source: Nova Scotia Round Table on Environment and Economy (1992); Premier's Round Table on Environment and Economy (1993); P.E.I. Department of Environmental Resources (1994, 1995); Ministère de l'Environnement et de la Faune du Québec (1996).

important for wildlife habitat, water purification, shoreline protection, estuarine productivity, hunting, and birdwatching. Provincial governments are now developing policies to designate and protect significant wetlands.

Sewage discharges

Sewage discharges have become a major stress on the ecosystem, threatening not only fish but also human health. Municipal wastewater is a major cause of contamination in shellfish growing areas, although non-point sources are also a factor (see Chapter 10). A 1994 survey found that 36% of shellfish growing areas subject to fecal pollution had been closed, covering an area of approximately 1 619 km² (Gray and Eaton 1994). This represented an increase of 9% over 1990 closures (Machell and Menon 1992). These closures cost millions of dollars in lost fisheries and have contributed to unemployment, declines in tourism, restriction of aquaculture, lost amenities, and higher prices to consumers (Fig. 10.23, Chapter 10).

Nitrogen and phosphorus in sewage discharges may stimulate plant growth and increase the blooms of toxic phytoplankton that contaminate shellfish, making them unsafe for human consumption. Heavy metals such as mercury, silver, chromium, lead, zinc, and cadmium accumulate in the aquatic food chain and can cause long-term problems for organisms. Although such metals occur naturally, most instances of contamination result from human activities. For example, consumptive advisories for mercury in fish have been issued in New Brunswick and Nova Scotia. Shellfishery closures in Belledune, New Brunswick, have been due to zinc and cadmium. Many synthetic organic chemicals are toxic to aquatic life and possibly harmful to humans. They find their way into municipal sewage systems through improper disposal of household chemicals and the discharge of contaminated industrial wastewater into the sewage system.

Sustainability of coastal zones

The coastal zone is being managed under an approach that considers the use of land and water resources and the interactions between human activities and the natural environment (Hildebrand 1989). The Atlantic Coastal Action Program (ACAP), a six-year initiative launched in 1991, has been developing comprehensive environmental management plans for 13 areas in Atlantic Canada (Box 7.5). New Brunswick has developed community-based watershed sustainable development initiatives (B.C. Jones, New Brunswick Department of Fisheries and Aquaculture, personal communication). The province is also leading a policy initiative on coastal zone development with special environmental considerations for residential and commercial properties to protect shellfish beds. Nova Scotia's Coastal 2000 is a framework for coastal zone management that includes safeguarding shellfish from land-based activities (Nova Scotia Department of the Environment 1994).

Box 7.4
Northumberland Strait Bridge

The Northumberland Strait Bridge, or Fixed Link, as it is popularly known, will run for 12.9 km over the Northumberland Strait, extending from Cape Tormentine, New Brunswick, to Borden, Prince Edward Island. It will replace the existing ferry service upon its opening in 1997.

Among its design specifications are the following:

- *design life: 100 years;*
- *basic structure: shore-to-shore bridge; no causeway component;*
- *structural materials: reinforced, post-tensioned concrete;*
- *length: 12.9 km, crossing the strait at its narrowest point;*
- *width: 11 m from guardrail to guardrail, including one lane and one emergency shoulder in each direction;*
- *typical elevation: 40 m off the water;*
- *typical clearance: 28 m off the water x 220 m wide;*
- *main bridge section: 45 spans, 11 080 m in total;*
- *P.E.I. approach bridge: 7 spans, 555 m in total; and*
- *N.B. approach bridge: 14 spans, 1 275 m in total.*

The developer, Strait Crossing Development Inc., has launched a study program to verify predictions of the impact of the project on the environment and to evaluate the effectiveness of mitigation measures. The Environmental Effects Monitoring (EEM) studies — which are being conducted during the preconstruction, construction, and operational phases of the project — are looking at environmental variables over time to detect changes caused by the project. A multidisciplinary EEM program advisory committee, consisting of regional experts in applicable marine and terrestrial disciplines, is helping to design the studies, ensuring they are scientifically and technically viable.

Biophysical components considered in the studies include:

- *terrestrial wildlife in areas such as the Cape Jourimain National Wildlife Area, Noonan's Marsh, and Amherst Cove Marsh;*
- *physical oceanography, including currents, tides, and sediment modelling;*
- *fisheries resources within the Northumberland Strait;*
- *ice climate and effects of ice scouring in the Northumberland Strait;*
- *marine and terrestrial species of concern;*
- *marine and terrestrial heritage resources; and*
- *freshwater resources near project activity areas.*

Source: Strait Crossing Development Inc. (1993).

The Nova Scotia government has also encouraged the formation of Regional Development Authorities (RDAs). These authorities are developing coastal resource inventory databases in cooperation with the federal Department of Fisheries and Oceans. The inventories will provide the basis for integrated coastal zone management. In 1994, a major international conference on coastal zone management, Coastal Zone Canada '94, was held in Halifax (Hildebrand and Nicholls 1995). The proceedings of this event (Wells and Ricketts 1994) provide one of the most comprehensive collections of international and Canadian papers on the topic. A "Call for Action" resulting from the conference, which includes many recommendations relevant to the maritime ecozones, was published in 1996 (Coastal Zone Canada Association 1996).

The State of the Atlantic Ecozones

In recent years, northwest Atlantic groundfish have suffered serious declines. A moratorium on commercial fishing begun in 1992 has been extended indefinitely. Some groundfish stocks are currently the smallest ever recorded. Atlantic Salmon stocks decreased steadily between 1980 and 1992 owing to excessive fishing and acid rain. In contrast, invertebrate catches on the Atlantic coast have increased in recent years. However, municipal wastewaters cause approximately 20% of the shellfishery closures. Aquaculture production increased steadily from about 38 t in 1982 to 9 000 t in 1991, then stabilized. Species include Atlantic Salmon, scallops, oysters, and mussels.

Ground-level ozone, especially urban smog, is a detriment to human health. Saint John is prone to sulphate aerosols and oxidants. Acidic fog is prevalent along the Atlantic coast, including the Bay of Fundy. Ozone also inhibits vegetation growth and causes agricultural crop losses.

Statistically significant decreases of 28–40% in sulphate concentration in precipitation (corrected for sea salt) have been observed since the mid- to early 1980s in Nova Scotia and New Brunswick. As a result, sulphate deposition has generally decreased; in 1980, most of the ecozone received sulphate deposition above 12 kg/ha per year, whereas in recent years it has received less than this value. This decrease is of the same order as the decreases (16.5% between 1980 and 1993) in sulphur dioxide emissions brought about internationally by Canada and the United States and, within Canada, among the eastern provinces.

Despite the above decreases in sulphate deposition, much of the ecozone is receiving deposition that is in excess of the critical load, which is estimated to be less than 8 kg/ha per year. Critical loads for aquatic ecosystems are based upon a freshwater pH of 6.0, below which many species of fish begin to disappear. However, these relationships between atmospheric deposition and lake pH were developed mainly for clear lakes, and more work needs to be done for the brown lakes, rich in organic compounds, that are common in the ecozone. Emission reductions beyond those undertaken in 1985 are needed to reverse the aquatic acidification that has already taken place.

The ecozone is expected to continue to be under attack from acid rain for the foreseeable future; continued monitoring of precipitation chemistry and impacted ecosystems will be required to determine the progress of control measures, as well as research into the effects of other pollutants on acidification (e.g., nitrogen, base cations) and further modelling studies to refine the projected impacts and to estimate the emission reductions that would be required to meet a specific deposition target.

Groundwater demands for domestic needs are increasing. Water quality is under increasing contamination threats from municipal, agricultural, forestry, and industrial sources. Each province is addressing water quality through community action programs and watershed management. The pollution effects of sewage discharges and urban stormwater runoff are also being addressed.

Forests comprise 90% of the ecozone's land cover and are important habitats for flora and fauna. Indigenous insects, such as Spruce Budworm and Hemlock Looper, have necessitated the use of pesticides and large-scale aerial spraying. However, beginning in 1995, such spraying was restricted, and the use of fenitrothion

Box 7.5
Atlantic Coastal Action Program

The Atlantic Coastal Action Program (ACAP) is a \$10-million initiative that will lead to blueprints for managing the coastal resources of 13 areas in Atlantic Canada. The areas are the Miramichi, Madawaska, Saint John, St. Croix/Passamaquoddy, and Letang areas in New Brunswick; the Annapolis River, Pictou, Sydney, and Lunenburg/Mahone Bay areas in Nova Scotia; the Cardigan Bay and Bedeque Bay area in Prince Edward Island; and the Humber Arm and St. John's areas in Newfoundland.

Community multistakeholder groups in each area organize the ACAP projects, which address environmental concerns — air, land, and water pollution — that threaten traditional ways of life and limit new employment opportunities in ecotourism and aquaculture. These groups develop comprehensive environmental management plans that integrate information on environmental quality and project objectives. From these plans, they are able to develop long-term strategies to maintain, restore, and enhance self-sustaining capacity in ecosystems.

Although ACAP does not pay for cleaning up the areas, it will fund demonstration projects using low-cost solutions. These solutions will have broader applications elsewhere.

Source: J. Ellsworth, Environment Canada, personal communication.

will be phased out by 1998. Beginning in 1996, a new biochemical, "Mimic" (tebufenozide), will be used against Spruce Budworm. Two model forests in the ecozone and incentive programs on private lands are increasing the sustainability of forest development.

Agriculture covers 9% of the ecozone. Farm size is increasing as the number of farms decreases, resulting in intensive production and large input of agrochemicals. The loss of soil organic matter is 15–30%, leading to better crop rotation programs. Risk of erosion by water is over 80% in each of the three Maritime provinces, especially in potato fields. The use of pesticides and mineral fertilizers is increasing. Drinking water standards are monitored for agrochemical content above 10 mg/L. However, non-point source nitrate leaching into groundwater has not increased in recent years. Environment Canada and Agriculture and Agri-Food Canada are investigating the environmental behaviour of pesticides and nitrates in climatic, topographic, and soil conditions.

Habitat loss as a result of forest clear-cutting and drainage of wetlands is the greatest threat to the ecozone's wildlife. Other threats are oil spills on land and sea. Each province is addressing these issues through wildlife policies and strategies. For aquatic habitats, the Department of Fisheries and Oceans has a strict policy of no net loss. Federal and provincial biodiversity strategies will help protect wetlands and genetic diversity. Protected areas represent 8.4% of the terrestrial ecozone, with 1.6% strictly protected. Each province is committed to completing a system of protected areas, including five Ramsar wetland sites, the most famous being the Bay of Fundy shorebird reserve.

Coastal ecosystems are of major importance, as much of the ecozone population lives near the coast. Chemical and physical stresses originate from industries, municipalities, resource extraction, and aquaculture. The Atlantic Coastal Action Program (ACAP) and Nova Scotia's Coastal 2000 are addressing coastal zone stresses from both ocean- and land-based activities.

As mentioned above, some vigorous steps are being taken to protect and preserve environmental quality and secure human health, and many of these efforts have been successful: polluted rivers and harbours have been rehabilitated; levels of contaminants have decreased; municipal and industrial effluents and emissions have been brought under control; recreational lands have been secured; and endangered species have been protected. This progress is due largely to the development and strengthening of laws, guidelines, and regulations aimed at controlling pollution and managing environmental resources.

Sustainability of the Atlantic ecozones

Assessments of ecosystem health are at a very early stage in Atlantic Canada. Data and information gaps exist for many areas of the terrestrial and marine environments. They must be filled before an operational definition of sustainable development can be developed and progress towards it monitored (Gray and Eaton 1994). The Ecological Monitoring and Assessment Network (EMAN) (Environment Canada 1996b) is helping to address these gaps (Box 7.6).

Use of the term sustainable development raises the questions, "Which environmen-

Box 7.6
Ecological Monitoring and Assessment Network

The national Ecological Monitoring and Assessment Network (EMAN) program is developing an interdisciplinary network of Ecological Science Cooperatives (ESCs) in each major Canadian ecozone to collect information on the functioning and condition of ecosystems. This information will be made available to individuals and organizations assessing, addressing, and reporting on the impacts of environmental stresses. National coordination of the EMAN is provided by Environment Canada's Ecological Monitoring Coordinating Office, based at the Canada Centre for Inland Waters in Burlington, Ontario (Environment Canada 1996b).

Each ESC is independent and sets its own research and monitoring agenda within an evolving national framework. ESC resources are primarily directed to scientific programs, rather than the creation of new organization structures. Some ecozones may require more than one ESC location. In this case, the ESC is itself a network of nodes, each of which focuses on selected issues and on the ecological impacts of specific stresses on the functioning of representative ecosystems.

The Atlantic Maritime ESC has four nodes:

- *Kejimkujik is located in inland Nova Scotia, with Kejimkujik National Park as the host institution. The ecological focus is atmospheric issues, biodiversity monitoring, and dynamics of aquatic systems.*
- *Fundy is located in southeastern New Brunswick at Fundy National Park. The ecological focus is forest ecosystems and forestry impacts.*
- *St. Andrews/Passamaquoddy is located in southwestern New Brunswick, with Huntsman Marine Science Centre/Department of Fisheries and Oceans as the host institution. The ecological focus is impacts on coastal systems, marine biodiversity, and chemical pollutants.*
- *Bedeque Bay is located in the Malpeque/Bedeque Bay area of Prince Edward Island. It has the Bedeque Atlantic Coastal Action Program site as the host institution. The ecological focus is agricultural impacts — surface runoff problems and reduced effects of intensive agricultural practices.*

Initiatives are under way to explore the potential for nodes to address impacts on marine systems in the Northwest Atlantic ecozone.

Source: R.D. Elliot, Environment Canada, personal communication.

tal properties must be sustained?" and "Which human uses of the environment must be sustained?" (Suter 1993). Conceptually, sustainability is understood in the ecozones as requiring a shift away from an anthropocentric view of environmental quality to one concerned with the health of the whole ecosystem and all its components (Gray and Eaton 1994). Over the long term, environmental protection in the ecozones will depend on a broad recognition that the environment and the economy are inextricably related. Success in putting these principles into action rests on an integrated partnership across the social spectrum, drawing full public, industry, and government participation.

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Chapter 8 Taiga Ecozones

Highlights

The three Taiga ecozones — the Taiga Plains, the Taiga Shield, and the Hudson Plains — stretch from the Mackenzie Delta to the coast of Labrador, covering almost a quarter of Canada. The cold climate allows for the widespread occurrence of discontinuous permafrost. Taiga ecosystems are less biologically productive and diverse than those farther south. The human population is small (65 000) and about 60% Aboriginal. In comparison with more southerly ecozones, the Taiga ecozones are not characterized by high levels of natural resource development and use.

■

Much of the Taiga is covered by comprehensive land claim agreements between governments and Aboriginal people or is currently the subject of comprehensive land claim negotiations. The scope of these negotiations includes land selection, wildlife harvesting, use of offshore areas, subsurface rights, resource revenue-sharing, and a role in decision-making with respect to management of the environment, economic development, and social programs.

■

Two major hydroelectric developments — Churchill Falls, Labrador, and La Grande, Quebec — lie within the Taiga, and a third, the Churchill–Nelson development in Manitoba, is partly in the Taiga. Together, these projects have a capacity of close to 23 500 MW of energy from stations in the Taiga Shield and Hudson Plains ecozones. To accomplish this, almost 3 000 m^3/s of river flow have been diverted to augment the water supply for generating stations, and approximately 14 300 km^2 of land, an area almost three times the size of Prince Edward Island, have been flooded in the Taiga to increase water storage capacity.

■

The environmental effects of hydroelectric developments in the Taiga have included changes in streamflow patterns and river ice conditions, the deterioration of aquatic habitat through enhanced production of methylmercury in reservoirs and accelerated erosion of susceptible shorelines, the substitution of aquatic for terrestrial habitat in flooded areas, and interference with fish movements.

■

Mineral potential is high in much of the Taiga, and development to date has focused on deposits of gold, silver, uranium, and iron. The discovery of large reserves of nickel, copper, and cobalt at Voisey's Bay on the Labrador coast has drawn considerable attention. Hydrocarbon potential is high in the Taiga Plains ecozone. The Norman Wells oil field, located under the Mackenzie River about 680 km northwest of Yellowknife, is the nation's fourth largest producer.

■

The environmental effects of mining activity in the Taiga are generally localized. Acidic effluent from mine tailings has caused contamination of nearby waters at three closed mines in the western Taiga Shield ecozone. In northern Saskatchewan, low-level radioactive tailings remain following the closure of several uranium mines. Air quality in the vicinity of Yellowknife has been impaired by emissions of arsenic and sulphur dioxide from the processing of gold-bearing ore.

■

A variety of contaminants have been found in Taiga food webs. Organochlorines, thought to originate outside the Taiga, have been detected in various species of fish, as well as mink and Caribou. Metals such as mercury and cadmium, which have both natural and anthropogenic origins, have been found in several species. Cadmium, for example, is present in the lichen–Caribou–human food chain. Although the levels are generally low in comparison with those in parts of southern Canada, many residents of the Taiga consume large amounts of country foods. In the Northwest Territories, for example, more than 70% of all Aboriginal households hunt or fish, and almost 25% trap. Residents of the Taiga Shield ecozone in Labrador, Quebec, and the Northwest Territories have been advised to reduce their consumption of Caribou kidneys and livers because of elevated cadmium levels.

■

Under climate change scenarios based on a doubling of atmospheric carbon dioxide, air temperatures in parts of the Taiga could rise 2–4°C in summer and as much as 10°C in winter within the next 100 years. While potentially benefiting activities such as agriculture and forestry, such a change in climate would instigate permafrost degradation, promote the occurrence of wildfire, and alter habitat characteristics.

■

The understanding of some key environmental conditions and trends in the Taiga has been hampered by a lack of baseline data. Some progress is being made, however, through initiatives such as the Environmental Information Partnership, established by the First Nations of the Moose River Basin and the Government of Ontario. The project aims to collect and manage baseline data as a foundation on which to assess the cumulative environmental impacts of development within the Moose River basin.

■

Various international, national, and regional initiatives exist that will contribute to addressing environmental concerns in the Taiga. These include the United Nations Framework Convention on Climate Change, Canada's Mine Environmental Neutral Drainage Program, which focuses on the development of new technologies to deal with acid mine drainage, and the Northwest Territories' Strategy for Renewable Resource Development.

■

Contents

GENERAL DESCRIPTION OF THE TAIGA

Introduction

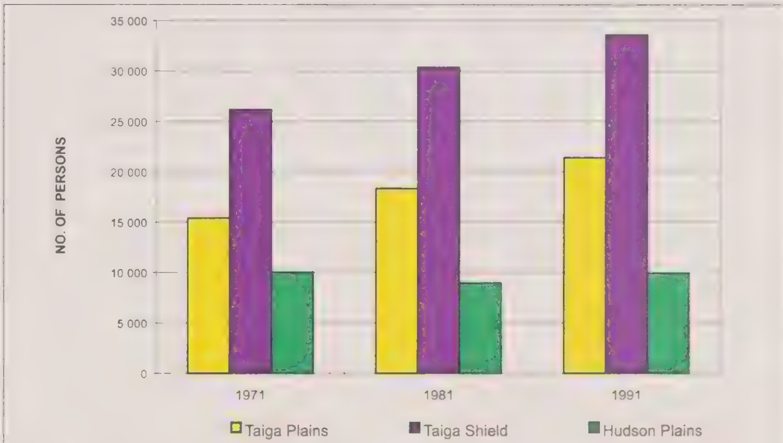
For environmental reporting purposes, the "Taiga" has been defined as the grouping of three terrestrial ecozones — the Taiga Plains, Taiga Shield, and Hudson Plains[1] (Fig. 8.1a). It is a vast territory, 2.375 million square kilometres in area (almost one-quarter of Canada), which arcs across the nation from the Mackenzie Delta in the extreme northwest to the Labrador coast in the east. The dominant vegetation cover is an open forest of small, slow-growing conifers, transitional between the closed-canopy boreal forest to the south and the treeless tundra to the north (Fig. 8.1e). Other characteristic features include:

- a sub-Arctic climate, marked by long, cold winters with persistent snow and ice cover;
- discontinuous permafrost (Fig. 8.2);
- numerous lakes and rivers and extensive wetlands;
- a transition from sub-Arctic to Arctic flora and fauna;
- a small human population (Fig. 8.1b), comprising about 60% Aboriginal people; and
- an economy based on traditional resource use, with areas of intensive natural resource development, notably hydroelectric developments and mine sites (see Figs. 8.6 and 8.8).

Figure 8.1a
Taiga ecozone boundaries, and selected communities in and around the Taiga

Source State of the Environment Directorate Environment Canada

Figure 8.1b
Population trends, 1971–1991



Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada, based on the 1991 Census. For further details, see Endnotes.

The **Taiga Plains** ecozone is the most western and northern of the three ecozones. The generally low terrain is dominated by the Mackenzie River and its many tributaries. The ecozone encompasses about 600 000 km^2, or 6% of Canada, largely in the western mainland Northwest Territories, but also in parts of eastern Yukon, northeastern British Columbia, and northwestern Alberta. It is bounded in the north by the Mackenzie Delta, in the west by the Mackenzie Mountains, in the south by the Boreal Plains ecozone, and in the east by the Canadian Shield. Great Bear and Great Slave lakes lie in the transition zone between the Taiga Plains ecozone and the Taiga Shield ecozone to the east.

The **Taiga Shield** ecozone is Canada's third largest ecozone, covering about 1.36 million square kilometres, or 14% of the nation. West of Hudson Bay, it includes over 400 000 km^2 of the southern Northwest Territories plus small sections of each of the three Prairie provinces. East of Hudson Bay, the ecozone includes almost half a million square kilometres of Quebec and much of Labrador. The terrain is generally rolling. Glaciers have moulded the land-

1. Information on adjacent marine areas is found primarily in Chapters 7 (Atlantic) and 9 (Arctic). Exceptions occur, however, where terrestrial–marine linkages form a necessary part of the discussion.

scape, exposing the ancient bedrock of the Canadian Shield, carving out depressions that are now occupied by lakes and wetlands, and leaving behind unconsolidated deposits such as moraines and eskers in other areas. Surface elevations west of Hudson Bay range from 200 to 500 m. East of Hudson Bay, they exceed 1 000 m in parts of central Quebec and in the Torngat Mountains of Labrador.

The **Hudson Plains** ecozone lies adjacent to Hudson and James bays, extending from northeastern Manitoba through northern Ontario and into western Quebec. The ecozone's total area of approximately 360 000 km^2 comprises about 3.6% of Canada. With the disappearance of glacial ice some 7 500–10 000 years ago and consequent rebounding of the Earth's crust, the Hudson Plains have emerged from beneath the Tyrell Sea. Measurements obtained at York Factory, Manitoba, indicate a current rate of emergence of between 0.6 and 1.0 mm per year (Canada Committee on Ecological Land Classification 1988). The resulting lowland is extremely flat and poorly drained, with an average gradient of less than 1 m/km. Wetlands and peatlands dominate the landscape, covering 85–90% of the ecozone. It is the most extensive wetland complex in Canada (see Fig. 10.12, Chapter 10) and the second largest peatland in the world.

Figure 8.1c
Population change in selected centres, 1971–1991

Selected centres	Population 1971	Population 1991	Population % change
Inuvik, N.W.T.	2 670	3 206	20
Norman Wells, N.W.T.	301	627	108
Fort Simpson, N.W.T.	747	1 142	53
Yellowknife, N.W.T.	6 122	15 179	148
Fort Nelson, B.C.	2 290	3 804	66
Brochet, Man.	N/A	229	N/A
Churchill, Man.	1 605	1 143	–29
Moosonee, Ont.	1 793	1 213	–32
Kuujjuaq, Que.	693	1 405	103
Schefferville, Que.	704[a]	303[b]	–57

Note: The geographic extent of a Census Metropolitan Area in 1971 may not correspond to that for 1991. For further details, see Endnotes.
N/A = not available.

[a] In 1971, Schefferville was classified as an unorganized nonmunicipality.
[b] 1991 data represent the population of the Village of Schefferville.

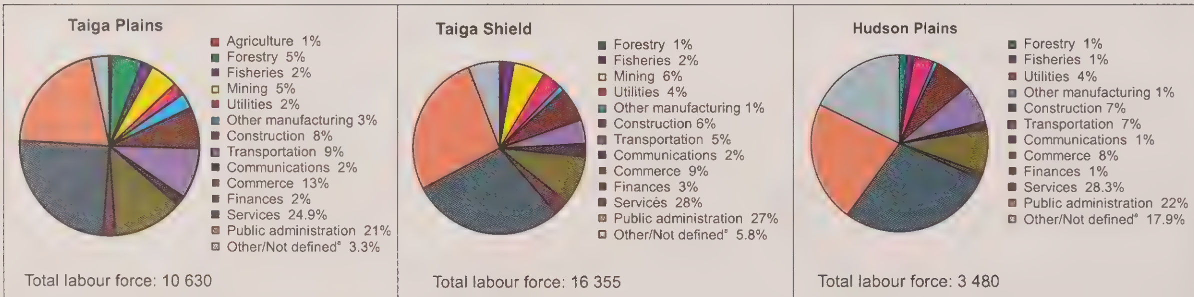
Source: Special tabulations prepared by Statistics Canada. For further details, see Endnotes.

Ecological setting

Climate, hydrology, and permafrost
The Taiga has a sub-Arctic climate, characterized by short, cool summers and long, cold winters. Mean annual air temperatures generally range from 0°C to –10°C, with mean January temperatures ranging from –30°C to –15°C and mean July temperatures from 10°C to 15°C (Fig. 8.1f). Winter temperatures can fall as low as –50°C, and summer temperatures can rise as high as 35°C.

Annual precipitation is low to moderate, ranging from 250 to 500 mm across much of the Taiga Plains and western Taiga Shield ecozones and up to 1 000 mm elsewhere. High precipitation along the coast of Labrador is the result of the cooling of

Figure 8.1d
Labour force composition, 1991



Note: Using the 1970 Standard Industrial Classification, the four primary sectors have been grouped with their respective first-stage resource processing industries. For further details, see Endnotes.

[a] "Other/Not defined" represents labour force categories that were less than 0.5% of the total labour force as well as responses for which the respondent did not specify the industrial category in which he/she or other household members were employed.

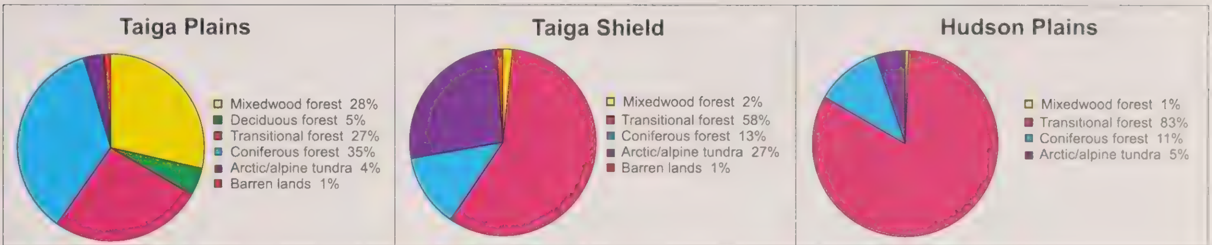
Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada.

moisture-laden air masses rising over the high terrain. Annual snowfall is generally in excess of 150 cm, and snow and ice covers persist for 6–8 months. The snow cover performs various ecological functions. For example, it acts as an insulator, shielding the ground from extremely cold temperatures and offering protection to small animals and plants in the winter. Deep snow, on the other hand, can interfere with the mobility and foraging success of herbivores, such as Caribou.

The cold climate has allowed for the formation of permafrost (i.e., permanently frozen ground) over much of the Taiga. In the extreme northwest, permafrost is virtually continuous and can extend to depths of up to 360 m in the Mackenzie Delta, 300 m near Inuvik, and 115 m at Norman Wells (Taylor and Judge 1975). Elsewhere, it is discontinuous in distribution, becoming more sporadic or patchy towards the southern limits of the Taiga. Figure 8.2 shows how far south permafrost extends around Hudson Bay. This is a consequence of the cooling influence of that vast water body, particularly during the summer season when sea ice lingers as late as July, only to begin forming again in late October.

One of the most important, and problematic, features of permafrost is ground ice. It can range from individual ice crystals to thick masses of pure ice. Ground ice content sometimes exceeds the saturated

Figure 8.1e
Land cover distribution



Note: For the definitions of land cover types, see legend to Figure 10.11, Chapter 10.

Source: National Oceanic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR) imagery; Manitoba Remote Sensing Centre, Manitoba Department of Natural Resources

Figure 8.1f
Air temperature, degree-days, and precipitation in selected centres

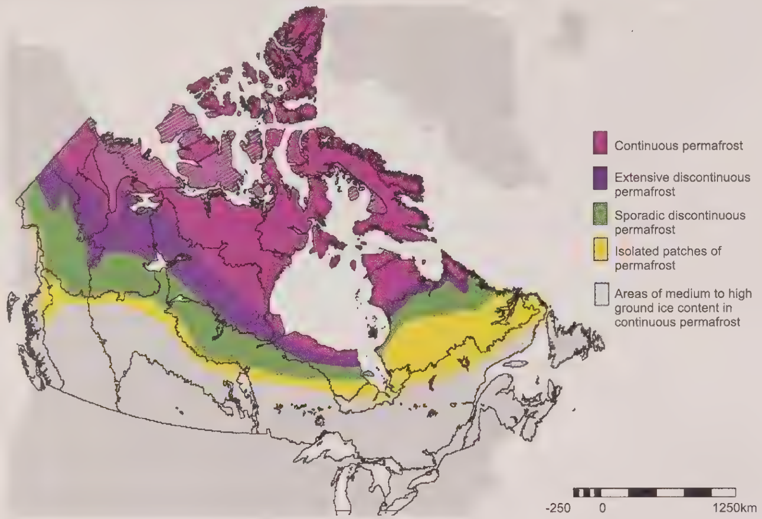
	Air temperature (°C)				Degree-days[a]		Precipitation			
Selected centres	Mean January maximum	Mean January minimum	Mean July maximum	Mean July minimum	Heating (<18°C)	Growing (>5°C)	Mean annual rainfall (mm)	Mean annual snowfall (cm)	Mean total precipitation (mm)	Days with measurable precipitation
Inuvik, N.W.T.	–24.1	–33.5	19.5	8.0	10 040	682	116	175	257	129
Norman Wells, N.W.T.	–23.6	–31.4	22.4	11.0	8 782	1 069	183	149	317	131
Fort Simpson, N.W.T.	–22.2	–31.3	23.4	10.3	7 976	1 195	210	164	361	124
Yellowknife, N.W.T.	–23.9	–32.2	20.8	12.0	8 477	1 039	154	144	267	118
Fort Nelson, B.C.	–17.7	–26.5	23.0	10.4	6 995	1 289	306	191	449	134
Brochet, Man.	–23.6	–33.3	20.8	10.8	8 390	965	256	185	440	N/A
Churchill, Man.	–22.9	–30.9	16.9	6.8	9 177	562	235	200	412	148
Moosonee, Ont.	–14.3	–26.9	21.8	8.4	7 092	1 078	500	225	700	169
Kuujjuaq, Que.	–19.0	–28.2	16.6	5.4	8 675	492	262	271	524	176
Schefferville, Que.	–18.4	–28.6	17.2	7.6	7 231	604	402	415	793	208

Note: Data based on 1961–1990 climatic normals.
NA = not available.

[a] A unit of measurement of the deviation of the mean daily air temperature from a predetermined standard (at a particular location). For further details, see definition of degree-days in Glossary.

Source: Environment Canada (1994a).

Figure 8.2
Permafrost zones in Canada



Note: Southern alpine occurrences in British Columbia and Alberta are not shown.
Source: Natural Resources Canada (1995).

moisture content of its host terrain, a phenomenon known as "excess ice." When permafrost containing excess ice thaws, the ground subsides in proportion to the volume of excess ice, an event referred to as "thermokarst." Ground ice is therefore a major obstacle to many types of development in cold regions. Thermokarst may result from natural or anthropogenic disturbances to the permafrost. Knowledge about the distribution and other characteristics of massive ground ice and ice-rich sediments is necessary to assess thermokarst's potential impacts. In parts of the Mackenzie valley (Hunt et al. 1974) and delta (Pollard and French 1980; Mackay 1989, 1995), massive ice and ice-rich sediments are widespread.

Geology and soils

The Taiga Shield consists of a mosaic of ancient geological formations, called "provinces," that together comprise a substantial part of the Canadian Shield, the foundation of the North American continent. Granitic plutons and metamorphic rocks such as gneiss and greenstone predominate. Some of the geological provinces are among the oldest on Earth, and some rocks date back more than 3 billion years. Volcanic intrusions are found in many areas, notably where major fault lines have developed.

During the Paleozoic era, which began about 0.57 billion years ago, much of the Canadian Shield was covered with seawater. Sedimentary rock layers up to 3 km thick were deposited in the Hudson and James bay area, including the Hudson Plains ecozone, and in the interior platform of western North America, including much of the Taiga Plains ecozone. Thus, both the Hudson Plains and the Taiga Plains ecozones are characterized by sedimentary rock formations of varying depth.

Soils vary considerably across the Taiga, but generally speaking they are acidic, nutrient-poor, and thin. In the Taiga Plains ecozone, soils are stony, except in the valleys of the Mackenzie, Liard, and Hay rivers, where silt deposits have created deeper, nutrient-rich soils.

Permafrost exerts a strong influence over several aspects of Taiga geomorphology. A variety of unique landforms, such as ice-wedge polygons and palsas (mounds or ridges of peat or peaty earth containing perennial ice and a core of permafrost), are the consequence of massive ice formation in the ground. The low permeability of permafrost soils effectively eliminates infiltration of surface water and influences groundwater availability and movement.

Flora and fauna

Throughout the Taiga, cool air temperatures, a short growing season, and recent glaciation have resulted in lower biological productivity and diversity than in the more southerly parts of Canada. The few plant species that thrive have adapted to the harsh climate and poor soils. Because of the cold conditions, dead vegetation does not decompose readily into soil but is preserved in the form of peat, which covers most low-lying areas. Black Spruce is the most prevalent tree species. In the Taiga Plains and Taiga Shield ecozones, other common species include White Spruce, Jack Pine, Tamarack, Paper Birch, Trembling Aspen, and Balsam Poplar. Willows and alders are the most common shrubs. Species common in Taiga ground cover include lichens (such as species of the genera *Cladina* and *Cladonia*, which provide the main food of the Caribou), mosses, heaths (e.g., Labrador Tea and Leatherleaf), and berry-producing species, such as cranberries, currants, and blueberries. Wetlands are dominated by sphagnum moss, shrubs, and, where conditions permit, Black Spruce and Tamarack. There is a general gradation in vegetation with latitude from forest to forest–tundra, which consists of a forest subzone and a shrub subzone (Payette 1983). Along the northern edge of the Taiga, the shrub subzone grades into the shrub tundra of the southern Arctic.

Wildfire has been instrumental in the development of a mosaic of plant communities. With a high proportion of resinous conifer species, Taiga forests are particularly vulnerable to fire. Fire burns about 1% of the taiga in the Northwest Territories each year. The area so affected varies from year to year, depending primarily on the weather. Studies in

northern Quebec have revealed a northward decline in average fire frequency from about once every 100 years in the forests near the 55th parallel to once every 9 320 years in the shrub tundra near the 59th parallel (Payette et al. 1989). Many birds and mammals require a variety of local vegetation communities, and wildfire produces that variety. Wildfire also contributes to renewal of ecosystems. The burning of vegetation releases vital nutrients and fosters the germination of seeds. Black Spruce and Jack Pine are among the species that release their seeds only under the high temperature conditions associated with wildfire.

Taiga habitats are essential to the life cycles of many species of birds. Approximately 210 species of birds occur regularly in the Taiga. Some characteristic Taiga species are listed in Table 8.1. Huge numbers of waterfowl use the coasts, lakes, and wetlands in the Taiga ecozones as staging or nesting areas. Much of the eastern populations of Brant and Lesser Snow Geese stage along the shores of James and Hudson bays (Bellrose 1980), as do large numbers of ducks (Ross 1982, 1983, 1984). The Hudson Plains ecozone provides breeding habitat for some 875 000 Canada Geese (Ontario Ministry of Natural Resources 1993). Also, many North American shorebirds breed in the Taiga ecozones, especially near Hudson Bay. The Ontario shore of James and Hudson bays provides crucial staging habitat for migratory shorebirds, particularly Semipalmated Sandpipers, Red Knot, and Hudsonian Godwit (Morrison et al. 1995).

Of the common large freshwater fish species, Burbot, Lake Whitefish, Longnose Sucker, and Northern Pike are the most widespread (Table 8.1). The growth rate of freshwater fish is relatively low everywhere in the Taiga. Important anadromous and marine fish species are Arctic Charr, Northern Cod, turbot, and Atlantic Salmon.

There are over 40 species of terrestrial mammals in the Taiga Plains ecozone, approximately 40 in the Hudson Plains ecozone and the Taiga Shield ecozone west of Hudson Bay, and about 30 in the Taiga Shield ecozone east of Hudson Bay (Banfield 1974). Some of the more wide-ranging species are listed in Table 8.1. Caribou, both Barren-ground and Woodland, are of particular economic importance. The Bluenose, Bathurst, Beverly, and Qamanirjuaq (formerly Kaminuriak) herds of Barren-ground Caribou winter in the Taiga Plains ecozone and the Taiga Shield ecozone west of Hudson Bay and migrate north to calving grounds in the tundra each spring (Fig. 8.3). The George River herd of northern Quebec and Labrador is the largest Caribou herd in Canada. The Leaf River herd is found in northwestern Quebec, in both the Taiga Shield and the Southern Arctic ecozones. The less abundant Woodland Caribou is found in, and south of, the Taiga across Canada.

Other wide-ranging mammals of economic significance include the Black Bear, Moose, and several furbearers, such as beaver, Muskrat, mink, marten, Red Fox, and Timber Wolf. Polar Bears inhabit the coastal zone of Hudson and James bays, Ungava Bay, and the northern Labrador coast. For more information on Polar Bears, see Chapter 9.

Two-thirds of the 3 000 Wood Bison in Canada range freely in the Mackenzie Bison Sanctuary on the northwest shore of Great Slave Lake. This is one of five recovery herds for this threatened species. Two other much smaller recovery herds are also located in the Taiga Plains ecozone, at Nahanni–Liard and at Hay–Zama. Other threatened and endangered species in the Taiga are listed in Table 8.2. See Chapter 10 for additional information on threatened and endangered species.

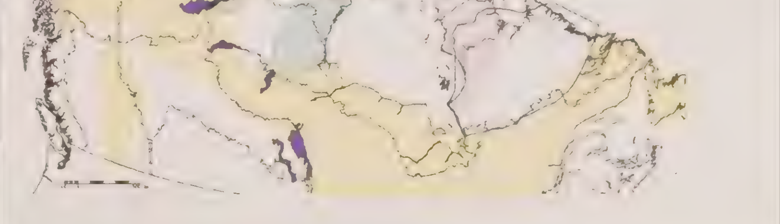
Socioeconomic setting

Population

Although the Taiga covers almost one-quarter of Canada, it is home to only 0.24% of the total population. About 60% of people in the Taiga are Aboriginal. In 1991, the population of the Taiga was approximately 65 000 people, about 13% more than in 1981 and 26% more than in 1971 (Fig. 8.1b). However, while the population of both the Taiga Plains and Taiga Shield ecozones grew steadily from 1971 to 1991, the population of the Hudson Plains ecozone fell about 10% between 1971 and 1981 before returning to the 1971 level of approximately 10 000 in 1991. The largest community in the Taiga, Yellowknife, now accounts for almost one-quarter of the entire population. Yellowknife showed remarkable growth from 1971 to 1991 (Fig. 8.1c).

Figure 8.3

Caribou range, mainland Canada



Source: State of the Environment Directorate, Environment Canada

Table 8.1
Characteristic species in the Taiga

A. Terrestrial mammals

Insectivores
Shrew, American Water
Shrew, Masked
Shrew, Pigmy

Hares/rabbits/pikas
Hare, Snowshoe

Rodents
Beaver, American
Lemming, Northern Bog
Mouse, Deer
Mouse, Meadow Jumping
Muskrat
Porcupine, American
Squirrel, American Red
Squirrel, Northern Flying
Vole, Gapper's Red-backed
Vole, Heather
Vole, Meadow
Woodchuck

Carnivores
Bear, American Black
Bear, Polar
Ermine
Fox, Arctic
Fox, Red
Lynx, Canada
Marten, American
Mink, American
Otter, River
Weasel, Least
Wolf
Wolverine

Ungulates
Caribou, Woodland
Caribou, Barren-ground
Muskox

Source: Adapted from Banfield (1974).

B. Birds

Loons
Loon, Common

Waterfowl
Bufflehead
Canvasback
Duck, Ring-necked
Goldeneye, Common
Goose, Canada
Mallard
Merganser, Common
Scaup, Lesser
Teal, Green-winged
Wigeon, American

Eagles/hawks
Eagle, Bald
Goshawk, Northern
Hawk, Red-tailed
Osprey

Grouse
Grouse, Sharp-tailed
Grouse, Spruce

Shorebirds
Godwit, Hudsonian
Sandpiper, Spotted
Snipe, Common
Yellowlegs, Lesser

Gulls
Gull, Bonaparte's
Gull, California
Gull, Herring

Owls
Owl, Great Gray
Owl, Great Horned

Woodpeckers
Flicker, Northern
Woodpecker, Hairy
Woodpecker, Three-toed

Perching birds
Blackbird, Rusty
Chickadee, Boreal
Crossbill, Red
Flycatcher, Least
Jay, Gray
Junco, Dark-eyed
Kinglet, Ruby-crowned
Raven, Common
Robin, American
Sparrow, American Tree
Sparrow, Fox
Sparrow, Lincoln's
Sparrow, White-crowned
Sparrow, White-throated
Thrush, Hermit
Thrush, Swainson's
Warbler, Blackpoll
Warbler, Connecticut
Warbler, Magnolia
Warbler, Orange-crowned
Warbler, Palm
Warbler, Tennessee
Warbler, Yellow
Warbler, Yellow-rumped
Waterthrush, Northern

Source: D. Fillman, P. Latour, and K. Ross, Environment Canada, personal communication.

C. Key freshwater fish species

	Taiga Plains ecozone	Hudson Plains ecozone	Taiga Shield ecozone	
			(west)	(east)
Burbot	X	X	X	X
Charr, Arctic				X
Cisco, Lake		X	X	X
Grayling, Arctic	X		X	
Inconnu	X			
Pike, Northern	X	X	X	X
Redhorse, Shorthead		X		
Salmon, Atlantic				X
Sturgeon, Lake		X		
Sucker, Longnose	X	X	X	X
Sucker, White	X	X	X	X
Trout, Brook		X		X
Trout, Lake	X		X	X
Walleye	X	X		X
Whitefish, Lake	X	X	X	X
Whitefish, Round	X		X	X

Source: W. Franzin, Department of Fisheries and Oceans, personal communication.

Labour and employment
Labour force statistics are provided in Figure 8.1d and Table 8.3. These data relate only to the wage economy and do not reflect nonwage employment, such as harvesting for subsistence.

Resource-based employment is comparatively low and has fluctuated considerably owing to changing market conditions. International market conditions are a key determinant of a mine's viability. Boycotts against natural fur products have affected Canadian trappers since the early 1980s.

A noteworthy characteristic of the Taiga labour force is the disparity in levels of wage employment between Aboriginals and non-Aboriginals. For example, according to a 1994 survey of all persons 15 years of age or older in the Northwest Territories, the non-Aboriginal rate of participation in the labour force was 89%, but the Aboriginal rate was only 61%. Overall participation rates in Inuvik, Norman Wells, and Yellowknife, which all have a non-Aboriginal majority, were 82%, 86%, and 87%, respectively. In contrast, participation rates in Aboriginally dominated Aklavik, Fort Norman, and Rae–Edzo were only 55%, 68%, and 52%, respectively (Government of the Northwest Territories 1994a).

Table 8.2
Endangered and threatened mammals, birds, fish, and plants, by Taiga ecozone, according to the Committee on the Status of Endangered Wildlife in Canada

Endangered species	Threatened species
Taiga Shield ecozone	
Mammals Whale, White (Beluga, Ungava Bay population) Wolverine (eastern population)	**Mammals** Whale, White (Beluga, eastern Hudson Bay population)
Birds Duck, Harlequin Falcon, Anatum Peregrine	**Fish** Cisco, Shortjaw Sculpin, Great Lakes Deepwater
Taiga Plains ecozone	
Birds Crane, Whooping	**Mammals** Bison, Wood
	Fish Sculpin, Great Lakes Deepwater
Hudson Plains ecozone	
Plants Gentian, White Prairie	**Fish** Cisco, Shortnose

Source: Committee on the Status of Endangered Wildlife in Canada (1995). Ecozone information compiled by M.J. Kerr-Upal based on the COSEWIC information in combination with range/distribution maps from COSEWIC status reports and various published wildlife authorities.

Table 8.3
Income statistics, 1991

Ecozone	Total income (% of Canadian total)	Per capita income ($, 000s)	Estimated GDP (% of Canadian total)
Taiga Plains	0.07	14.9	0.09
Taiga Sheild	0.12	17.1	0.19
Hudson Plains	0.02	10.2	0.02
Canada	100.00	17.1	100.00

Source: Special tabulations prepared by Statistics Canada. For further details, see Endnotes.

Transportation
The network of roads and railroads is sparse compared with that in areas to the south (Fig. 8.4). Consequently, there is a landing strip in almost every village. Even some of the larger communities in the Hudson Plains ecozone and several communities in the Taiga Plains ecozone are accessible only by boat or air or by winter roads. The only significant port in the Taiga, at Churchill, Manitoba, is at the head of the Hudson Bay Railway on the west coast of Hudson Bay. The port offers a shorter sea route from the Prairies to Europe than the combined rail and shipping routes in southeastern Canada, and its grain terminal remains ice-free from mid-June to early November. Nonetheless, its use has declined in recent years.

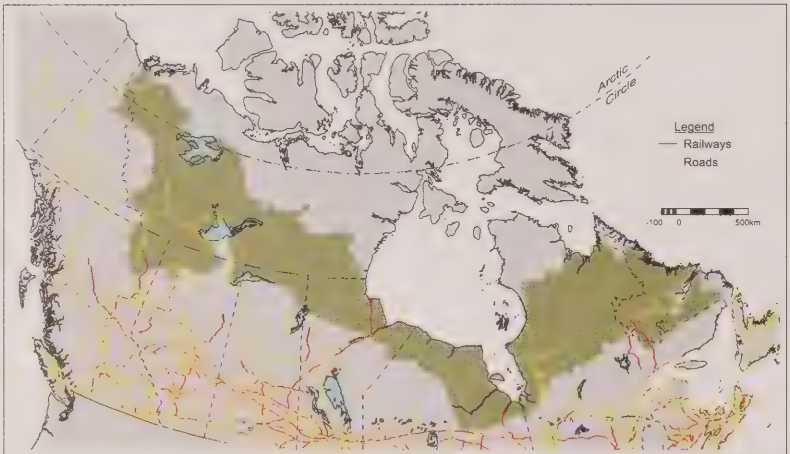
Land claims
The Taiga ecozones differ from most other Canadian ecozones in that much of their area is covered by provisions of comprehensive land claim agreements (Box 8.1; Fig. 8.5). These agreements variously provide for such things as increased self-government, greater control over education, special systems of policing and administration of justice, resource royalties, guaranteed wildlife harvesting rights, and participation in decision-making respecting renewable resources, land use planning, environmental impact assessment, and land and water regulation.

Subsistence lifestyle
Traditional Aboriginal lifestyles are inextricably linked to wildlife resources. In the Northwest Territories, for example, more

than 70% of all Aboriginal households hunt or fish, and almost 25% trap. Over 99% of Aboriginal households consume country foods (Government of the Northwest Territories 1994b). Additional information on the importance of country foods in the Taiga is presented in Table 8.4.

A concern in an extensive area of southern Labrador and adjacent Quebec is the effect of low-level flying on wildlife. The area is being used for low-level flight training by the Canadian military and pilots from other North Atlantic Treaty Organization (NATO) countries (Box 8.2). The activity has been subjected to an environmental assessment and review, and one of the recommendations of the review panel was for the establishment of a joint Canada/Labrador/Quebec Caribou Management Board for the George River herd.

Figure 8.4
Roads and railroads in Canada, 1981



Source: National Atlas Information Service, Natural Resources Canada.

Figure 8.5
Main Aboriginal land claims in the Taiga, July 1996

Disclaimer: Apart from the James Bay Territory, the Inuvialuit Settlement Region, the Gwich'in Settlement Area, the Nunavut Settlement Area, and the Sahtu Settlement Area (finalized agreements), the areas indicated on this map represent only approximate boundaries of the areas in which the various Native groups have claimed an interest. The precise delineation of these areas for each claimant group will be determined as negotiations proceed on the separate claims settlements.

Source: Department of Indian Affairs and Northern Development.

HUMAN ACTIVITY AND THE ENVIRONMENT

In comparison with more southerly Canadian ecozones, the Taiga ecozones are not characterized by high levels of renewable resource use. Except in the southern Taiga Plains ecozone, agriculture is virtually impossible owing to the short growing season and poor soil conditions. Commercial forestry is also limited in potential. Although almost a third of the land surface of the Taiga Plains ecozone, or 171 000 km^2, has been classified as "timber-productive" forestland, the corresponding amount in the Taiga Shield ecozone is only about 8%, or 105 000 km^2, and in the Hudson Plains ecozone, about 4%, or 15 000 km^2. There are some commercially significant forests of White Spruce, Jack Pine, Balsam Poplar, and Trembling Aspen in the valleys of the Fort Nelson, Liard, Hay, Slave, and Mackenzie rivers and in the Cameron Hills of the Taiga Plains ecozone. The allowable annual cut in the Northwest Territories is estimated at 200 000 m^3 of sawtimber, but the harvest for all uses was only 45 000 m^3 in 1990, when only one commercial sawmill was operating, at Hay River (Government of the Northwest Territories 1994b). With the reopening of a sawmill at Fort Resolution (located in the Boreal Plains ecozone on the south side of Great Slave Lake), the Northwest Territories timber harvest rose to 90 000 m^3 in 1993–1994.

Wildlife resources, on the other hand, have provided better opportunities. In addition to the subsistence activities already noted, there is a commercial fishery on Great Slave Lake, the catch consisting mostly of Lake Whitefish. In 1992, the total value of Lake Whitefish, Northern Pike, Lake Trout, Inconnu, and Burbot landed from Great Slave Lake was \$1 344 000, more than the value of the

commercial fishery on Lake Superior, although considerably smaller than that on Lake Manitoba. The Inuit of Kuujjuaq (located on the south side of Ungava Bay) operate a commercial Atlantic Salmon fishery on the Koksoak River, and the Waswanipi Cree Nation also runs a small commercial fishery. In addition, sport fishing, hunting, and wildlife viewing have become important tourist attractions in various parts of the Taiga. A well-known example is the viewing of Polar Bears in the vicinity of Churchill, Manitoba.

Two major hydroelectric developments, Churchill Falls, Labrador, and La Grande, Quebec, lie entirely within the Taiga, and a third, the Churchill–Nelson development in Manitoba, is partly in the Taiga. Together, these three projects produce approximately 23 500 MW of energy from stations in the Taiga Shield and Hudson Plains ecozones. This combined capacity has been achieved through the diversion of almost 3 000 m^3/s of river flow, an amount comparable to the average annual flow of the Fraser River at Hope, B.C., and the flooding of approximately 14 300 km^2 of land in the Taiga Shield ecozone, an area almost three times the size of Prince Edward Island.

Mineral potential is high in the Taiga Shield ecozone. A deposit containing uranium, radium, silver, and cobalt was discovered at Port Radium in 1930. The Eldorado mine operated there over much of the period between 1933 and 1982. In 1934, a gold rush on the north shore of Great Slave Lake gave birth to what is now the city of Yellowknife. Production started at the Con mine in 1938 and at the Giant mine in 1948. The discovery of diamonds in the Lac de Gras area about 300 km northeast of Yellowknife, just outside the Taiga, was announced in 1991. This precipitated a rush of exploratory activity in the surrounding area, including parts of the Taiga Shield ecozone. East of Hudson Bay, major iron ore deposits were known to exist in the Knob Lake region of central Quebec as early as 1895. The first shipment of iron ore left Schefferville in 1954, following the completion of a rail line to Sept-Îles.

Box 8.1
Comprehensive land claims

There are two general categories of Aboriginal land claims in Canada — specific and comprehensive. Specific claims relate to problems arising from the administration of Indian treaties, the Indian Act, *Indian funds, and disposition of Indian land. Comprehensive claims are based on the concept of continuing Aboriginal rights and title that have not been dealt with by treaty or other legal means. Comprehensive claims cover about half of Canada, particularly in the Northwest Territories and Yukon, but also in northern Quebec, Labrador, Ontario, and British Columbia. Settlements of comprehensive claims typically entail aspects such as money, land, forms of local government, rights to wildlife, and rights associated with the protection of Native language and culture.*

The James Bay and Northern Quebec Agreement was settled in 1975. The claim was initiated in 1971 by the Cree and Inuit in response to Hydro-Québec's announcement of plans to construct the La Grande hydroelectric complex. As a result of the settlement, the Cree and Inuit received, among other things: (1) the right to hunt, fish, and trap in the Agreement area; (2) a substantial degree of self-government in their own communities; and (3) a cash settlement of $225 million to be paid out over 25 years. Three categories of land were established. In and around Aboriginal communities, 13 700 km² of territory were put under the control of the local residents (Category I land). Exclusive hunting, fishing, and trapping territories were also designated — 70 000 km² for the Cree and 81 600 km² for the Inuit (Category II land). In the remaining territory, Aboriginals were granted exclusive rights to 22 important species of game and freedom to harvest timber for their own needs (Category III land).

In 1976 and 1977, Canada accepted comprehensive claims from the Dene and Métis of the Mackenzie Valley in the Northwest Territories. Negotiation of a joint Dene/Métis claim began in 1981. An agreement was initialled by negotiators in April 1990. In July 1990, the Dene and Métis, at their assemblies, voted not to proceed with ratification of the agreement. The Gwich'in and Sahtu Dene and Métis did not agree with this action and withdrew from the Dene/Métis negotiating group. They requested regional settlements. In November 1990, the government discontinued negotiation of the Dene/Métis claim and authorized the negotiation of separate regional settlements, based on the April 1990 agreement, with any of the five Dene and Métis regions that might request it. The Gwich'in of the Mackenzie Delta region were the first to negotiate an agreement, and it came into effect at the end of 1992. The settlement provided the Gwich'in with a cash settlement and approximately 24 000 km² of private land, 4 299 km² of which includes mineral rights, and it entitled the Gwich'in to a share of resource royalties from the Mackenzie Valley. The settlement also guaranteed rights to wildlife harvesting and Gwich'in participation in decision-making bodies dealing with renewable resources, land use planning, environmental impact assessment review, and land and water regulation.

The Sahtu Dene and Métis were the second of the Mackenzie Valley regional groups to seek a comprehensive land claim. Their final agreement was signed in September 1993 and came into effect in June 1994. The agreement provides the Sahtu Dene and Métis with a cash settlement and 39 624 km² of land, 1 813 km² of which includes mineral rights, and other benefits similar to those provided in the Gwich'in settlement.

The Inuvialuit Final Agreement and the Tunngavik Federation of Nunavut, which were settled in 1984 and 1993, are mentioned in Chapter 9, as they cover primarily Arctic territory. Yukon land claims are discussed in Chapter 3. Other claims relating to portions of the Taiga that were in negotiation as of February 1996 were the North Slave Dene and Métis claim in the Mackenzie Valley, the Atikamekw and Montagnais claim in Quebec and Labrador, the Labrador Inuit Association claim, and the Innu Nation claim of most of Labrador.

Table 8.4
The importance of country foods at various locations in the Taiga

Location	Importance of harvesting	Source
Total bush harvest		
Cree and Chipewyan Indians and Métis living at Fort Smith[a] and Fort Chipewyan	Country meat, birds, and fish accounted for one-third of the consumption of meat, birds, and fish; young people consumed less country food than did their elders	Wein et al. (1991)
Eight Cree communities on the Ontario side of Hudson and James bays	Replacement value of bush harvest in 1990 was $8 400 per family, regional average	Berkes et al. (1994)
Eight Cree communities on the Quebec side of Hudson and James bays	Minimum of 121 kg of animal food per person per year; an estimated 45–55% of weight of food and the majority of protein and micronutrients in the diet	James Bay and Northern Quebec Native Harvest Research Committee (1982)
Subsistence fishery		
Eight Cree communities on the Quebec side of Hudson and James bays	Fish averaged about 15% of the harvest of animal food in the 1970s	James Bay and Northern Quebec Native Harvest Research Committee (1982)
Aboriginals across Canada	Average of 42 kg/year (which is six times the average Canadian fish consumption)	Berkes (1990)
Harvest of waterfowl (ducks, geese, and swans)		
Aboriginals in coastal Labrador	Average of 60 ducks and 2 geese per person per year	J.S. Wendt and K.M. Dickson, unpublished data
Eight Cree communities on the Quebec side of Hudson and James bays	Waterfowl averaged 25% of the harvest of animal food in the 1970s (in coastal communities, 29–44%)	James Bay and Northern Quebec Native Harvest Research Committee (1982)
Coastal Cree communities on the Quebec side of Hudson and James bays	20 ducks and 61 geese per hunter per year	J.S. Wendt and K.M. Dickson, unpublished data
Human consumption of meat from furbearers (muskrat, beaver, etc.)		
Aboriginals across Canada (based on three studies in the Taiga and three close by in the Boreal Plains and Boreal Shield ecozones)	Average of 21–53% of all wild food (including berries, fish, mammals, birds), 1912–1982	Various studies cited in Todd and Boggess (1987)
Total for Ontario	Estimated $2.38 million in 1972–1973	Novak (1975), cited in Todd and Boggess (1987)
Eight Cree communities on the Quebec side of Hudson and James bays	16% of the harvest of animal food	James Bay and Northern Quebec Native Harvest Research Committee (1982)
Human consumption of big game (Moose, Caribou, Black Bear)		
Eight Cree communities on the Quebec side of Hudson and James bays	Average of 33% of the harvest of animal food for all communities (over 50% at three inland communities)	James Bay and Northern Quebec Native Harvest Research Committee (1982)

[a] Fort Smith is just outside the Taiga Shield ecozone in the Boreal Shield ecozone.

The 1993 discovery of large reserves of nickel, copper, and cobalt at Voisey's Bay on the Labrador coast, approximately 35 km southwest of Nain, probably will lead to further development of a new mining area. Oil and gas potential exists in the sedimentary deposits of the Taiga Plains ecozone. To date, the most significant find was the 1921 discovery of oil beneath the Mackenzie River about 60 km downstream from Fort Norman. The founding of Norman Wells ensued, and modest oil production continues from this deposit.

The Taiga is also affected by human activities in surrounding ecozones and in other parts of the world. Atmospheric circulation in the northern hemisphere, especially in winter, renders the Taiga susceptible to pollution from industrialized regions of North America, Europe, and Asia. The source of contaminants found in the Taiga is not always clear. Some substances, such as mercury, can have both distant, anthropogenic sources and local, natural sources. (See Chapter 9 and the "Atmosphere" section of Chapter 10 for additional information on sources and pathways of contaminants.) Potentially, contaminants can also be "imported" by waters flowing into the Taiga from other parts of Canada and by migratory wildlife that have been exposed to contaminants outside the Taiga.

Climate change has the potential to significantly alter Taiga ecosystems and hence human activity in the region. Analysis of air temperature records dating back to about 1900 suggests that there has already been significant warming, as much as 1.8°C, in the Taiga Plains ecozone and the Taiga Shield ecozone west of Hudson Bay. In the Hudson Plains ecozone, little overall change in temperature has occurred since about 1900; in the Taiga Shield ecozone east of Hudson Bay, a minor warming of approximately 0.2°C has been estimated since 1916 (D. Gullett, Atmospheric Environment Service, Environment Canada, personal communication).

The following sections of this chapter examine the main human-related influences on the Taiga environment — namely, hydroelectric development, nonrenewable resource extraction, the long-range transport of contaminants, and climate change. The overall objective is to examine what is happening, why it is happening, why it is important, and what is being done about it.

Box 8.2
Low-level flying over Labrador

Since 1980, the airfield at Happy Valley–Goose Bay in Labrador has been used for low-level flight training by several NATO air forces. Under a Multinational Memorandum of Understanding (MMOU), pilots train to avoid radar detection by using "terrain masking," which includes, among other tactics, flying along river valleys in central Labrador at altitudes lower than 300 m. Nonexplosive practice weapons are also released against ground targets in a designated practice target area of 175 km² that lies 100 km south of Happy Valley–Goose Bay. There are no permanent settlements in the low-level training areas. The training program is opposed by the Labrador Innu and the Quebec Montagnais, who have traditionally hunted, trapped, fished, and camped in portions of the areas used for the low-level flights, including the wildlife-rich river valleys. But the majority of Labradorians support the program.

With the pending expiry in 1996 of the existing MMOU, the Department of National Defence proposed to negotiate a new one that would allow for an increase in the number of flights. There would be a rise from a maximum of 6 000–7 000 flights over a 30-week period to a maximum of 18 000 over a 39-week period per year as of 1996. A maximum of 15 000 flights would occur under 300 m, with approximately 15% of these flying as low as 30 m. Night flights could increase from about 50 a year to a maximum of 1 400.

A federal environmental assessment panel conducted public hearings into the department's proposal, visiting 14 communities in Labrador and Quebec in fall 1994. Its findings were released in early 1995 (Canadian Environmental Assessment Agency 1995). The panel recommended that the federal government approve the proposal subject to the recommendations of its report, concluding that, "in the short term, severe negative economic effects would result from Project termination, and there is little evidence at this time to suggest that the Project will cause significant negative environmental, social or health impacts." However, the panel found that "the scientific basis for predicting the effects of the Project on wildlife, natural systems and human health is weak in many areas. Despite more than 14 years of military low-level flying, there are few sound data on the effects of low-level flying on human health, on wildlife or on the environment in general. That state of ignorance should not be allowed to continue."

Among its 58 recommendations, the panel called for the establishment of the Labrador Institute for Environmental Monitoring and Research. The institute would "advise on the terms and conditions governing low-level flying" and would "manage a program of research and monitoring in support of this advisory role." In December 1995, the federal government announced its decision to establish the institute. Other recommendations of the panel related to the need for surveys and studies of specific species, including Osprey, Bald Eagle, Harlequin Duck, and Caribou.

(For more background on the low-level flying issue, see DND [1994] and Canadian Environmental Assessment Agency [1995]. For additional information, contact the Goose Bay Office of the Department of National Defence in Ottawa.)

Table 8.5
Some characteristics of major hydroelectric developments affecting the Taiga

Project, owner, operational date	Capacity (MW)	Area of reservoir (km²)	Area flooded (km²)	Diversions (25 m³/s or more flow)
Taiga Shield ecozone				
Churchill Falls, Newfoundland and Labrador Hydro, 1971	5 428.5	5 698	2 640	Into the Churchill River 196 m³/s from the Julian and unknown rivers 200 m³/s from the Naskaupi River 130 m³/s from the Kanairiktok River
La Grande complex, Hydro-Québec, 1980–1985 (Phase 1) and 1991–1996 (Phase 2)	15 719	15 613	11 505	Into the La Grande River 845 m³/s from the Eastmain andOpinaca rivers 31 m³/s from Lake Frégate 790 m³/s from the Caniapiscau River
Hudson Plains ecozone				
Churchill–Nelson, Manitoba Hydro, 1973–1992	2 310[a]	1 173[b]	151[c]	Into the Nelson River 765 m³/s from the Churchill River

[a] 2 310 MW is the capacity of two generating stations in the Hudson Plains ecozone. Three other stations in the Churchill–Nelson development are in the Boreal Shield ecozone.
[b] 1 173 km² is one-half of the total area of Southern Indian Lake, whose shores are in the Taiga. The rest of Southern Indian Lake and four other reservoirs (Lake Winnipeg, Cedar Lake, Stephens Lake, and Sipiwesk Lake), which are part of the Churchill–Nelson development, are outside the Taiga.
[c] 16 km² were flooded by the two generating stations, and 269 km² were flooded on Southern Indian Lake, one-half of which (135 km²) is in the Taiga. Additional areas were flooded at reservoirs outside the Taiga.

Source: Day and Quinn (1992); K. Adams, Manitoba Hydro, personal communication.

Hydroelectric development

Background

Since the 1960s, Canada has diverted more water than any other country (Day and Quinn 1992), most of it for three large hydroelectric projects. Two of these, the Churchill Falls project in Labrador and the La Grande ("James Bay") complex in Quebec, are located within the Taiga Shield ecozone (Fig. 8.6). Reservoirs associated with those projects have flooded a total of approximately 14 150 km² in the Taiga, creating water bodies that cover about 21 300 km² (Table 8.5). The third project, the Churchill–Nelson development in Manitoba, straddles the Taiga Shield, Hudson Plains, and Boreal Shield ecozones. Hence, it is also discussed in Chapter 5.

Figure 8.6
Major hydroelectric developments affecting the Taiga

Source: State of the Environment Directorate, Environment Canada.

Newfoundland's Churchill Falls generating station in Labrador is the third largest hydro development in Canada. It was constructed between 1966 and 1974 and at that time was the largest civil engineering project ever undertaken in North America. Eighty dikes were constructed to create the Smallwood and Ossokmanuan reservoirs. A huge underground powerhouse was built, and power began flowing from the site in 1971.

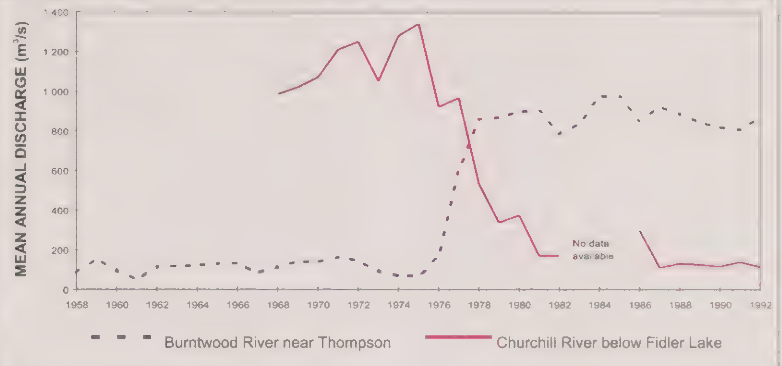
The La Grande hydroelectric complex has been developed in two phases and has entailed the diversion of flows from the Caniapiscau River to the east and the Eastmain and Opinaca rivers to the south. These diversions have almost doubled the La Grande River basin area to nearly 177 000 km². A land surface area of 11 505 km² was flooded in the process of creating

seven reservoirs. Construction is completed on La Grande Phase 1 and continues on Phase 2. The project incorporates the largest underground powerhouse ("LG-2") in the world. In total, there are nine generating stations. Over 700 km of asphalt road were constructed linking Radisson near LG-2 to Matagami in the south.

The Churchill–Nelson hydro development in northern Manitoba has, to date, involved the construction of five generating stations on the Nelson River. The lowest two facilities, Long Spruce and Limestone, are within the Hudson Plains ecozone. In addition, most of the Churchill River flow has been diverted to the Nelson River (Fig. 8.7). This was accomplished by building a control structure at the outlet of Southern Indian Lake on the Churchill River, thereby elevating the lake surface 3 m. This allowed water to flow into a diversion channel and from there via the Rat and Burntwood rivers to the Nelson River. Diversion of flow from the Churchill to the Nelson began in 1976 and averages 765 m^3/s.

In northern Ontario, there are hydroelectric developments on the Abitibi and Mattagami rivers of the Moose River basin. These are actually located in the Boreal Shield ecozone (see Chapter 5) and are comparatively small facilities that operate as run-of-the-river systems with no major reservoirs. There is also some small-scale hydroelectric generation in the western part of the Taiga. In the Northwest Territories, there are developments at Taltson River (Twin Gorges and four small units), on the Snare River (Snare Rapids, Snare Falls, and Snare Forks are owned by the Northwest Territories Power Corporation and Snare Cascades by the Dogrib Nation), and at Blue Fish near Yellowknife. None of these sites includes diversions. There is a small hydroelectric facility north of Lake Athabasca, Saskatchewan, near Tazin Lake. Water is diverted from Tazin Lake into Lake Athabasca.

Figure 8.7
Effects of water diversion on river flows



Source: Environment Canada (1994b)

Table 8.6
Some effects of hydroelectric developments

Impacted system	Effect
Aquatic ecosystems	Physical and chemical processes Reversal of the natural seasonal flow pattern of rivers Increased evaporative water losses Altered siltation patterns Increased turbidity Altered river ice regimes Changes in water temperatures Biological processes Gain in freshwater habitat Disruption of fish spawning routes Growth of some fish populations in reservoirs Increased levels of methylmercury
Terrestrial ecosystems	Loss of terrestrial habitat Disruption of animal habitat and migration routes
Littoral ecosystems	Destruction of shoreline and shoreline habitat (creation of dead zones) around reservoirs owing to fluctuating water levels Riverbank erosion downstream from dams
Atmosphere	Greenhouse gas production by decomposition of vegetation in inundated areas
Humans	Economics Altered wildlife resource base Sociocultural effects Relocation of population in flooded areas Loss of archaeological heritage Health effects of methylmercury Dietary changes Political and legal challenges Transportation systems Disrupted

Source: Adapted from OECD (1988); Linton (1991).

Environmental effects

Effects of hydroelectric development vary greatly, as does the extent of scientific knowledge about these effects (Table 8.6). In the case of the La Grande complex, for example, a broad program of monitoring and research was initiated in the early 1970s to address recognized gaps in understanding and to provide baseline environmental information for assessing changes caused by the hydroelectric development. This program, carried out in three phases (1972–1979, 1979–1985, and 1985–2000), has involved the participation of several federal and Quebec provincial agencies, the Société de développement de la Baie James, the Société d'énergie de la Baie James, and various consultants and university groups. A range of biophysical studies has been carried out, the evolution of new environments (i.e., reservoirs, rivers with modified flow, and diversion routes) has been studied, and water quality, fish, and mercury in the environment have been monitored.

Diversion of flow

Hydroelectric development in areas of relatively low elevation and relief, such as the territory surrounding Hudson and James bays, usually necessitates an augmentation in flow by interbasin diversion so as to optimize the project's operation (Rosenberg et al. 1995). As already noted, the Churchill–Nelson development entailed the diversion of most of the Churchill River flow into the lower Nelson River. As part of the La Grande project, 90% of the flow of the Eastmain and Opinaca rivers was diverted into the lower La Grande, and 40% of the flow of the Caniapiscau River was diverted into the upper La Grande. The Caniapiscau flows northward into the Koksoak River, which discharges into Ungava Bay below Kuujjuaq. Diversion of Caniapiscau flow has resulted in a 30% reduction in mean annual flow of the Koksoak River.

Reservoirs

Creation of a reservoir entails the flooding of land and whatever vegetation it supports. At La Grande, the first consequences in newly created reservoirs were an increase in phosphorus and a decrease in pH. Submerged organic matter began to decompose, consuming dissolved oxygen, further lowering the pH of the water, and releasing carbon dioxide and nutrients. In the second or third year after flooding, phytoplankton populations began to rise, followed by an increase in zooplankton.

An unwelcome impact of flooding vegetated areas to create reservoirs is the enhanced production of methylmercury (see Chapter 5). In poorly oxygenated waters and sediments, such as those found in newly flooded reservoirs, the amount of methylmercury in the food web rises above baseline levels. The formation of methylmercury, an organic form of mercury, occurs through both microbial reactions and abiotic processes. In its elemental form, mercury passes through the digestive system of animals without

Table 8.7

Mercury levels in fish in drainage basins affected by hydroelectric development

Hydroelectric development	Location	Species	Mercury concentration (ppm): Predevelopment	Mercury concentration (ppm): Postdevelopment	Year(s)
Churchill Falls, Labrador	Smallwood Reservoir	Northern Pike[a]		1.00	1978
				1.00	1987
		Lake Trout[a]		1.52	1978
				1.07	1987
Churchill–Nelson, Manitoba	Southern Indian Lake	Walleye[a]	0.2–0.3		1972–1976
				0.60	1978
				0.75	1979
				0.55–0.61	1994
		Northern Pike[a]	0.3–0.5		?–1978
				0.90	1979
				0.39–0.47	1994
Hydroelectric development	**Location**	**Species**	**Mercury concentration (ppm): Range**	**Mercury concentration (ppm): Mean**	**Year(s)**
La Grande complex, Quebec	28 natural lakes	Longnose Sucker[b]	0.06–0.32	0.16	Since 1978
		Lake Whitefish[b]	0.07–0.30	0.16	
		Northern Pike[a]	0.25–0.90	0.61	
		Walleye[a]	0.32–1.26	0.68	
		Lake Trout[a]	0.22–1.10	0.71	

[a] Piscivorous species.

[b] Nonpiscivorous species.

Source: *Churchill Falls* and *La Grande*: Brouard et al. (1990); *Churchill–Nelson*: Government of Canada–Government of Manitoba (1987); Strange (1995).

significant uptake. However, methylmercury is readily absorbed and poorly eliminated by vertebrates. It biomagnifies through the food web, such that concentrations in piscivorous (fish-eating) fish are typically higher than in nonpiscivorous fish, and concentrations in animals that consume a lot of piscivorous fish (e.g., Osprey, mink) are greater still. At high levels, methylmercury is toxic. The level at which it becomes toxic varies among species and individual organisms. Canadian guidelines for maximum total mercury in fish for human consumption are 0.5 parts per million (ppm) for fish sold commercially and a recommendation of 0.2 ppm for First Nations people where fish comprise a substantial proportion of an individual's dietary protein (Health and Welfare Canada 1979).

Table 8.7 presents data on mercury levels in various fish species in the Smallwood Reservoir, Labrador, Southern Indian Lake, Manitoba, and natural lakes within the territory of the La Grande complex, Quebec. Mercury levels in Walleye taken by the commercial fishery on Southern Indian Lake, Manitoba, averaged between 0.2 and 0.3 ppm during 1972–1976. Impoundment of the lake occurred in 1976; mercury levels in Walleye rose to almost 0.6 ppm in 1978 and peaked at over 0.75 ppm in 1979. Mercury levels in Northern Pike averaged between 0.3 and 0.5 ppm until 1979, when they rose to almost 0.9 ppm (Government of Canada–Government of Manitoba 1987). By 1994, mercury concentrations in whitefish appeared to have declined to preimpoundment levels at two sites on Southern Indian Lake. Although displaying greater year-to-year variability, mercury levels in pike and Walleye in 1994 were lower than their maximum recorded levels (Strange 1995).

At the La Grande complex in Quebec, fish have been monitored for mercury since 1978, and information has been gathered in both natural water bodies and reservoirs. In natural water bodies, a wide range in mercury concentrations has been found for individual fish species in different lakes. Levels in piscivorous fish have been approximately four times higher than levels in nonpiscivorous species, sometimes exceeding the Canadian marketing standard of 0.5 ppm. Following impoundment, mercury levels in all monitored species within reservoirs rose. For example, five years after impoundment, concentrations were 4–5 times higher than preimpoundment concentrations in Lake Whitefish and Longnose Sucker, but levels started to decline thereafter (Brouard et al. 1990).

Johnston et al. (1991) cited studies that suggest that the return to normal mercury concentrations may take five years or it may take decades, depending on factors such as the diet of individual fish species, the presence or absence of reservoirs upstream, and the acidity and temperature of water in individual reservoirs. The size and type of inundated vegetation are also important. A confounding factor that can delay the return of mercury concentrations to baseline levels is thermal erosion, the erosion of ice-rich permafrost by the combined thermal and mechanical action of moving water (Box 8.3).

Reservoirs have other effects on fish, apart from methylmercury contamination. In general, the creation of large reservoirs favours fish species that adapt to quiet waters, such as the Lake Whitefish, over species that prefer rapids, such as the Brook Trout (Hydro-Québec 1993b).

Some recent research has been undertaken to examine the role that hydroelectric reservoirs play in the production of greenhouse gases (Rudd et al. 1993; Kelly et al. 1994). The flooding of upland forests and peatlands to create reservoirs may boost the transfer of carbon dioxide and methane to the atmosphere. Taking into account both forest fires and photosynthesis, northern forests are thought to be neither a source nor a sink (absorber) of carbon dioxide in the long term. However, peatlands and lakes act as carbon dioxide sinks. Forests are net absorbers of methane, whereas peatlands are minor sources. To determine what effect reservoir creation had on these greenhouse gases, initial measurements were made at several sites within the La Grande complex in August 1992. Results suggested that the reservoirs were net sources of both carbon dioxide and methane. More studies have since been undertaken to follow up on these initial findings.

Downstream effects

The harnessing of a river for hydroelectric development typically results in an alteration in the pattern of river flow. Taiga river flows are normally lowest in the winter, rising to an annual maximum in spring when the snow melts. The strategy in hydroelectric generation is to store water for release in winter to meet the peak power demands.

Box 8.3
Reservoir shoreline instability: the case of Southern Indian Lake

Prior to the damming of the outlet of Southern Indian Lake, Manitoba, in 1976, 76% of the lake's shoreline was predominantly bedrock. When the desired higher water level was achieved, only 14% of the shoreline was bedrock. The fine-grained, ice-rich silts, clays, and organics that made up much of the shoreline were particularly vulnerable to erosion caused by strong wave activity — and the long fetches on the 2 000-km² lake allowed large waves to form. A study of shoreline erosion was conducted during the first four years after impoundment (1977–1980) at 20 representative sites surrounding the lake. Over that period, the extent of shoreline retreat varied widely; the maximum annual value was 12 m, which entailed the erosion of 23 m³ of material per metre (Newbury and McCullough 1984). Although some of this sediment was discharged from Southern Indian Lake, much of it was deposited within 300 m of shore. The amount and type of flooded organic matter are the most important factors affecting the production of methylmercury and thus the duration of the mercury problem. The influx of new organic material from eroding shores — soil, peat, and vegetation, including trees — into Southern Indian Lake has probably enhanced the rate of methylmercury production in the lake.

This causes a smoothing out or even a reversal of seasonal discharge extremes. Flow on the lower Nelson River below Kettle Dam is now usually highest in the winter, although summer flow remains close to the predevelopment level because of the addition of diverted Churchill River flow. Diurnal variations in flow well beyond natural conditions can also occur as hydroelectric authorities strive to meet variations in energy demand over the course of a day. At Kettle Dam on the lower Nelson River, most day-to-night drops in hourly mean discharge were greater than 2 000 m^3/s in winter and commonly almost 3 000 m^3/s in summer from 1979 to 1988. Prior to development, between 1959 and 1974, the largest 24-hour change in discharge at an upstream site, Bladder Rapids below Cross Lake, was less than 400 m^3/s (Federal Ecological Monitoring Program 1992).

Flow reduction on the lower Eastmain and Opinaca rivers resulted in the erosion of exposed riverbanks in the first years after diversion. The volume of eroded material fell by 90% four years after flow reduction. The Eastmain took on the characteristics of flow from the remaining tributary areas, becoming more turbid and richer in nutrients.

Modification of river flows also has implications for estuaries and shoreline habitats. Estuaries are areas of immense biological productivity because of unique conditions created where fresh water and salt water mix. Prior to flow diversion, fresh water occupied the 27-km-long Eastmain River estuary. Flow reduction allowed salt water to penetrate about 10 km upstream of the river mouth in summer and up to 15 km in winter. Most benthic organisms and fish followed this shift of the mixing zone upstream, and fish populations remained abundant.

On the lower La Grande, the LG-1 dam acts as a barrier to anadromous fish and the tide. The major modification in water quality in the lower La Grande below LG-2 has been a change in its temperature. As the water intake for the LG-2 powerhouse is at a depth of 25 m in the reservoir, water below LG-2 is colder in summer and warmer in winter than under natural conditions. Fishing yields have been similar to those before the creation of the LG-2 reservoir. Immediately below LG-2, mercury levels in Lake Whitefish are noticeably higher than those in the reservoir because the fish have adopted a piscivorous diet.

The northeast coast of James Bay is of special importance to migrating and moulting duck populations in terms of both species diversity and numbers (Reed et al. 1996). Studies of habitat use have established the importance of certain coastal environments such as tidal flats, eelgrass beds, and shoal areas in supporting duck populations. The variety of habitats is attractive to geese and ducks for their different biological activities (Dignard et al. 1991). Although they occur elsewhere along the northeast coast of James Bay, it is worth noting that eelgrass meadows were absent from the La Grande and Eastmain estuaries both before and after the construction of the La Grande development. Ten years of monitoring in the James Bay region have revealed large variations in eelgrass shoot density and dry leaf biomass, with depth, with season, and from year to year. Climatic conditions and water levels have a direct influence on the annual production of eelgrass. In the longer term, isostatic rebound has a dominant influence on the distribution of eelgrass beds. A decrease in surface water salinity beneath winter ice cover, attributable to increased discharge of the La Grande, has had little, if any, negative impact on eelgrass. During the growing season, coastal water salinity has been comparable to natural conditions (Lalumière et al. 1994; Julien et al. 1996). Reed et al. (1996) found little evidence of deterioration in subtidal and intertidal duck habitats, but they cautioned that it is premature to conclude that none has, or will, occur.

Cumulative effects

Finally, little is known about the cumulative effects of the La Grande and Churchill–Nelson projects (Sallenave 1994). Concerns about cumulative effects arose when Hydro-Québec proposed the Grande-Baleine development. In response, Hydro-Québec chose 10 environmental themes for cumulative effects analysis. Each theme was studied at one of four geographic scales that ranged from the territory governed by the James Bay and Northern Quebec Agreement to the global level. Although some of the conclusions remain the subject of controversy, Hydro-Québec found that few measurable, detectable cumulative effects would result from the construction of the Grande-Baleine complex. Cumulative impacts on climate, on mercury, on changes in freshwater plumes of developed rivers, and on most species were thought to be "local and selective." It was felt that the Grande-Baleine and La Grande complexes might have cumulative impacts on waterfowl, Caribou, biodiversity, the greenhouse effect, and the human environment (Hydro-Québec 1993a).

Effects on people

In Quebec, fish comprised as much as 15–20% of the Crees' country food prior to commencement of the La Grande complex. Blood mercury screening programs conducted from 1971 to 1978 and from 1979 to 1982 had shown that 40% of the Aboriginal population in Quebec had blood mercury levels higher than the World Health Organization's acceptability criterion of 20 parts per billion (ppb). In 1986, the James Bay Cree, Hydro-Québec, and the Quebec government established the James Bay Mercury Committee. One of the first things the committee did was review the mercury monitoring program that had been in place for some years to ensure that it was running properly. The committee encouraged people to avoid those species of fish known to have the highest mercury levels and investigated and promoted alternative food sources, such as Canada Geese (Hydro-Québec 1994).

In winter, water level and flow fluctuations upstream and downstream of a generating station can disrupt travel as a result of poor ice conditions (e.g., shoreline ice fractures, ice ridges, and slush ice) or reduction in ice cover. For example, increased winter streamflow and higher water temperatures in the lower La

Grande River meant that ice did not form as it used to, and Cree hunters from Chisasibi had to travel greater distances than before to reach hunting areas on the opposite (north) shore. To solve the problem, a road was built along the north shore, using the most downstream dam, LG-1, as a bridge to the road (Rosenberg et al. 1995).

Outlook

Energy demand has not increased as projected since the early 1990s, and several large projects have been postponed. However, it is possible that more power will eventually be sought to serve increasing populations to the south and potential mines or other developments in the North. Future hydroelectric developments in the Taiga could include the following:

- Hydro-Québec's Grande-Baleine complex, situated to the north of La Grande, with a potential capacity of 3 100 MW; an environmental assessment was initiated in accordance with the James Bay and Northern Quebec Agreement and the federal environmental assessment and review process, but this assessment was not completed because the project was shelved;
- Hydro-Québec's Nottaway–Broadback–Rupert complex, with a potential capacity of 8 400 MW;
- a 1 380-MW generating station at Conawapa, 25 km downstream from Limestone on the lower Nelson River; however, a proposal to develop the site in the early 1990s was shelved, and Manitoba Hydro's 1995 20-year capital expenditure forecast does not include a new hydroelectric project in the Taiga; and
- Gull Island and Muskrat Falls on the lower Churchill River in Labrador.

Although Ontario Hydro's plans to build or extend 11 generating stations on the Moose, Abitibi, and Mattagami rivers (Ontario Hydro 1989) have been postponed, the extension of a 12th site was approved in 1994. Some of those sites are outside the Hudson Plains ecozone, but they affect the amount and timing of water flowing through its rivers and estuaries.

Mining and hydrocarbon production

The resource base

The Canadian Shield is rich in mineral potential. However, there are few operating mines in the Taiga Shield ecozone, except in the extreme west around Yellowknife. Many promising deposits exist that, depending on metal prices, could be developed. The Taiga Plains ecozone is an important oil- and gas-producing area. In the Hudson Plains ecozone, mineral potential has been difficult to assess owing to thick glacial debris and layers of sedimentary rock that inhibit exploration of the underlying Precambrian bedrock. However, the recent discovery of diamond-bearing kimberlitic pipes in the James Bay lowland has spurred increased mineral exploration activity by Canadian and foreign companies.

Figure 8.8 shows active and inactive mine sites in the Taiga. Mines in the Yellowknife area produce primarily gold and silver, with arsenic as a by-product. Northern Saskatchewan is the world's largest producer of uranium — 27% of the world's supply in 1994. In the past, uranium was mined at three Taiga sites in northern Saskatchewan; since 1980, however, all uranium mining in the province has been south of the Taiga. In the eastern Taiga Shield ecozone, a number of open-pit iron ore mines operated in the Schefferville area from the mid-1950s to 1982. Iron ore is still mined in the Labrador City–Wabush area, just south of the Taiga in the Boreal Shield ecozone (see Chapter 5).

Mineral exploration is occurring in many parts of the Taiga. Two areas just north of Great Slave Lake, the Yellowknife Supracrustal Belt and the Russell Lake–Indin Lake areas, are actively mined for gold and base metals, and the lower part of the District of Keewatin is mined for gold (DIAND 1993). In addition, the discovery of diamonds in the Lac de Gras area of the southern Arctic about 300 km northeast of Yellowknife has resulted in exploration activity in the neighbouring Taiga Shield ecozone.

At Voisey's Bay, Labrador, initial mineable resources of 31.7 million tonnes of nickel, copper, and cobalt were announced in June 1995. A further resource potential of 50 million tonnes was announced in January 1996. This important new find presents significant economic and employment opportunities for Aboriginal and other Canadians.

Figure 8.8
Mining areas and oil and gas pipelines in the Taiga

Source: State of the Environment Directorate, Environment Canada

Known hydrocarbon resources are concentrated in the Mackenzie Valley (Fig. 8.8). The Norman Wells oil field is the nation's fourth largest producer. Estimated recoverable reserves total 37.5 million cubic metres, more than half of which had been produced by mid-1994 (DIAND 1994a). The oil deposit at Norman Wells is under the Mackenzie River, and some of the drilling is done from natural and artificial islands. There is a small oil refinery at Norman Wells, from which diesel fuel and other products are shipped by barge to Mackenzie Valley communities such as Inuvik.

A major expansion of production facilities at Norman Wells and construction of a pipeline (Fig. 8.8) along the Mackenzie Valley to Zama, Alberta, in the early 1980s raised the field's daily output from about 500 m^3 to levels at times exceeding 5 000 m^3. Six artificial islands were built in the Mackenzie River, and some 160 new injection and production wells were drilled to boost the field's output. Plans call for a further 11 wells to be drilled.

The Pointed Mountain (N.W.T.) and Kotaneelee (Yukon) gas fields are located on the Liard Plateau. The former, discovered in 1967, has been producing gas steadily since 1972, for a total of 8.6 billion cubic metres up to 1993. The latter, located some 35 km to the southwest, had produced 1.3 billion cubic metres by 1993. Gas from the two fields is piped to British Columbia. The National Energy Board estimates the magnitude of eight recently discovered gas pools near Fort Liard at 12.9 billion cubic metres (DIAND 1994b). In addition, extensive reserves of oil and gas are known to exist just north of the Taiga Plains ecozone in the outer Mackenzie Delta and Beaufort Sea (see Chapter 9).

Effects on the land

Exploration for nonrenewable resources takes place over a wide area, but much of the activity is of short duration and nonintrusive. If undertaken, trenching and stripping in ice-rich permafrost terrain can lead to thermokarst subsidence and erosion, but measures can be taken to reduce the likelihood of such an occurrence. For example, geophysical activities over sensitive terrain may be scheduled for the winter season when the ground is completely frozen and covered with a protective blanket of snow.

Permafrost and ground ice can also cause problems in the excavation and handling of mineral ore. High ice contents, which dilute ore and reduce the effectiveness of blasting, and "sticky" ore were reported to be factors contributing to the higher costs of mining and to the closure of mining operations in Schefferville.

In the extraction phase, open-pit operations generally have a greater impact on the landscape than underground operations. Near Schefferville, for example, open-pit mining of iron ore and the related facilities affected a surface area of 30 km^2 (ÉEM Inc. 1995). Where mining takes place underground, land is required for the mill and related facilities and for storage of tailings and waste rock.

The Norman Wells pipeline (Fig. 8.8), built in 1984–1985 and operated by Interprovincial Pipe Lines (NW) Ltd., was the first completely buried oil pipeline in the discontinuous permafrost zone of northern Canada. Measuring 324 mm in diameter and buried at a depth of 1 m, it extends 869 km from Norman Wells, N.W.T., to Zama, Alberta. The pipeline was designed to transport 4 800 m^3 of oil per day for 25–30 years. Normally, oil flowing through a pipeline is well above 0°C. In ice-rich permafrost, such warmth can cause differential settlement of the pipeline as the ground thaws around it. Thus, the Norman Wells pipeline was designed and constructed to minimize heating of the soil, and the oil was chilled at source to about –2°C. The thawing of sensitive slopes was controlled by covering the slopes with an insulating layer of wood chips up to 1.8 m thick. Engineers built the pipeline to withstand anticipated differential settlements by increasing the grade of the pipe and the thickness of the pipe wall. A monitoring program was developed to track the performance of the pipeline (Box 8.4).

Box 8.4
Pipelines and permafrost: monitoring the Norman Wells pipeline

The Permafrost and Terrain Research and Monitoring Programme was established by Interprovincial Pipe Lines and the Department of Indian Affairs and Northern Development to determine and quantify the impacts of the Norman Wells pipeline project, to minimize adverse environmental impacts, and to recommend improved environmental practices for the pipeline and future projects (MacInnes et al. 1989, 1990). The program was initiated prior to the construction of the pipeline in order to collect baseline data and was originally scheduled to last 5–10 years or until conditions stabilized. As of 1995, the pipeline had been monitored for 10 years, and, although a small leak occurred in May 1992, causing the pipeline to be shut down for a few days, no major problems had been observed.

Nevertheless, some concern has arisen from a decision made in August 1993 to introduce seasonal fluctuations in the temperature of the oil and to raise its average annual temperature from –2°C to 0°C. The main reason for this change was the large expense involved in chilling the oil in the summer months. The effect of the warmer oil is expected to be greatest along the first 100 km of the pipeline. The concern is that the insulated slopes could thaw, resulting in stresses on the pipe and a possible rupture.

Effects on water

When exposed to air, moisture, and bacteria, the sulphide minerals in the mine tailings and waste rock may oxidize and break down, producing weak sulphuric acid. In the absence of sufficient induced (e.g., traditional lime treatment) or natural (e.g., carbonate minerals) buffering, this acid may dissolve metals in the tailings and rock, resulting in the leaching and transport of these metals — a condition referred to as "acid mine drainage" or "acid rock drainage." The contaminated effluent can have serious effects on aquatic ecosystems unless prevented, treated, or contained (see Chapter 11).

Present-day tailings management usually consists of containment of the material in diked, shallow lakes, with subsequent treatment that can include covering the tailings with waste rock or layers of soil and possibly revegetation to stabilize the surface. In the past, some tailings have been deposited on land without ongoing treatment or sufficient containment.

In 1986, a survey was conducted of three abandoned mines in the Northwest Territories that were thought to have environmental problems associated with tailings: the Discovery gold mine on Giauque Lake, the Rayrock uranium mine on Sherman Lake, and the Thompson–Lundmark gold mine on Thompson Lake (Table 8.8) (Hall and Sutherland 1989). At the Discovery mine, tailings deposited on land were found to be eroding into Giauque and Round lakes. Earlier investigations had revealed that sediments in Giauque Lake were contaminated with mercury originating in the mine tailings. Fish in the lake had also been found to be highly contaminated with mercury (Moore et al. 1978), leading the Department of Fisheries and Oceans to post a warning to fishermen. The 1986 survey revealed increasing levels of mercury in lake sediments. It was suggested that the Discovery mine site could provide an opportunity to develop and demonstrate appropriate containment and reclamation techniques for acid-generating tailings (Hall and Sutherland 1989). Studies have been undertaken to determine the best options for remedial action, including costs; as of April 1996, however, no restoration work had been done.

At the Thompson–Lundmark site, deeper lake sediments were known to be elevated in metal content. The 1986 survey suggested that the metals could have been the result of contamination from the mine. However, the levels may be natural in origin, as drainage from the tailings was away from the lake. At Rayrock, N.W.T., both radionuclides and copper from the tailings were slowly seeping into water bodies. In Saskatchewan, in a 109-ha area north of Lake Athabasca near Uranium City, there are 10.6 million tonnes of low-level radioactive uranium mine and mill tailings (Statistics Canada 1994). Many small mines fed ore to mills at three principal mine sites in the ecozone: the Gunnar mine and mill operated from 1955 to early 1964; Lorado milled ore for three years in the late 1950s; and Eldorado Nuclear operated the Beaverlodge Lake mill from 1952 to 1982. Both Gunnar and Lorado were abandoned without proper decommissioning by the original owners. In 1988, the Saskatchewan government established the Abandoned Mine Program to assess all preexisting abandoned mines (not just uranium mines) and to take corrective action where necessary (Saskatchewan Environment and Public Safety 1991).

The Gunnar mill and tailings areas have never been decommissioned; the Lorado mill site was cleaned up in 1990, but the tailings area remains unreclaimed; and the Beaverlodge Lake mill and tailings area have been decommissioned, and transition-phase monitoring is ongoing (Saskatchewan Environment and Public Safety 1991). For a uranium mine, decommissioning entails meeting provincial and Atomic Energy Control Board standards for mine closure, tailings reclamation or rehabilitation, and dismantling of facilities.

Gunnar tailings are present at three sites. Two are on dry land and have been invaded by indigenous vegetation, except in one windblown location (Kalin 1979; Environment Canada 1993). The third disposal site is under water. Five million tonnes of tailings generated at the Gunnar mill were discharged into Mudford Lake between 1955 and 1964, and at some point failure of a dam released tailings into Langley Bay, a small bay of Lake Athabasca. Joshi et al. (1988) found both radioactive and nonradioactive material in the bottom sediments of Langley Bay. These sediments generate long-term radium-226, resulting in surface water concentrations of around 0.18 Bq/L (Environment Canada 1993). The Saskatchewan Surface Water Quality Objective for radium-226 is 0.11 Bq/L

Table 8.8

Acid rock drainage from abandoned mines in the Northwest Territories portion of the Taiga

Mine	Years of operation	Type of mine	Average yearly production (kg)	Wastes (1994) Type	Wastes (1994) Volume (t)	Comments
Discovery 63°11'12"N, 113°53'30"W	1950–1969	Underground for gold	1 685	Up to 46-year-old tailings and waste rock	1.1 million	Abandoned without treatment and containment. Tailings have eroded into Giauque Lake. On-land tailings releasing acidity to surface drainage.
Rayrock 63°26'54"N, 116°32'18"W	1957–1959	Underground for uranium		35-year-old tailings; also waste rock	71 000 (tailings)	Abandoned without treatment or containment over a 6- to 8-ha area. Tailings releasing copper and radionuclides to Marian River system.
Thompson–Lundmark 62°36'45"N, 113°28'15"W	1941–1943, 1947–1949	Underground for gold and silver	365 (gold) 71 (silver)	51-year-old tailings in aswampy area near a lake	134 000	Abandoned without treatment or containment. Some tailings releasing lead, copper, nickel, zinc, manganese, and arsenic to surface drainage.

Source: Hall and Sutherland (1989); DIAND (1994c).

total, and the Metal Mining Liquid Effluent Regulations limit for effluents is 0.37 Bq/L filtered as an average monthly mean. Environment Canada (1993) surveyed existing scientific research and found no evidence that radionuclide levels in Langley Bay are harmful to whitefish or Northern Pike.

The Lorado tailings contain iron sulphide minerals that have been discharged into Nero Lake and from there into Beaverlodge Lake. The tailings on land are thus acid-generating and have not been invaded by vegetation. In the late 1980s, the pH of Nero Lake was 2.3 (Intergovernmental Working Group on the Mineral Industry 1988), and the Saskatchewan Surface Water Quality Objective for radium-226 was exceeded. A dense growth of aquatic vegetation on the bottom of the lake appears to be helping to isolate the contaminated sediment from the lake water (Environment Canada 1993).

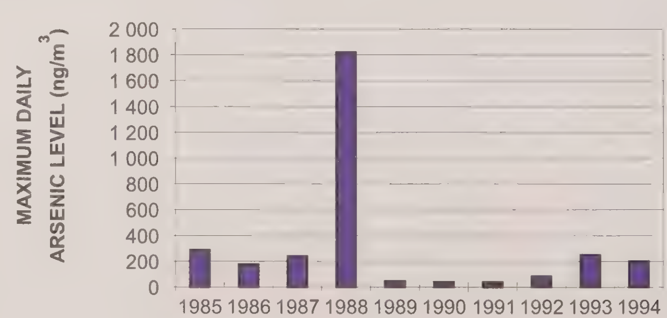
A few years ago, the Con Mine at Yellowknife constructed an "Autoclave" — a high-pressure oxidation plant. This plant treats arsenic-contaminated sludge from surface pits. Using oxygen and iron, a stable compound of ferric arsenate is formed and deposited into the mine's tailings pond. Thus, the sludge is treated to an environmentally acceptable level, and gold remaining in the sludge is recovered.

Effects on air

Air quality is a local concern in Yellowknife. The mineral arsenopyrite is associated with gold-bearing ore mined in the Yellowknife region. When the ore is "roasted," arsenic trioxide and sulphur dioxide are released. Annually averaged levels of arsenic recorded in downtown Yellowknife fell substantially after the overhaul of arsenic control equipment at the Giant Yellowknife mine in the mid-1970s. Maximum 24-hour sampling period values have also been lower since 1985, with the notable exception of 1988, when pollution control equipment malfunctions were reported (Fig. 8.9). Although higher than the four previous years, the 24-hour maximum level of 251 ng/m^3 in 1993 was still below the Ontario standard of 300 ng/m^3. There are no Northwest Territories or federal standards for arsenic in air (Government of the Northwest Territories 1995a).

Unlike emissions of arsenic trioxide, releases of sulphur dioxide from gold roasters have never been controlled in the Yellowknife area. Although other sources of the gas exist (e.g., fossil fuel combustion for heating and vehicle operation), studies undertaken in the 1970s concluded that the Giant mine roaster stack was the principal source in Yellowknife (Government of the Northwest Territories 1993). Sulphur dioxide emissions were estimated at 50–65 t per day. The main concern is the harm the acid-forming gas can do to vegetation; in fact, analyses of vegetation samples in the early 1990s revealed that damage to trees was occurring at least 5 km from the roaster stack. Air quality in downtown Yellowknife has also been affected. From August through November 1992, the 24-hour standard for sulphur dioxide (150 ng/m^3) was exceeded once, whereas the 1-hour standard (450 ng/m^3) was exceeded 20 times. In 1993, levels exceeded the 1-hour standard on 30 occasions over the 10 months that measurements were obtained, but the 24-hour standard was never exceeded. One suggested response to reduce emissions of the gas by 90–95% is to switch from the roasting technology to the advanced pressure oxidation technology of the Autoclave. However, the capital costs of doing so have been regarded as too high given the known reserves at the mine. Therefore, another proposal has been to increase the height of the roaster stack or increase the exit velocity of stack emissions. This would ensure that emissions disperse more widely, significantly reducing ground-level concentrations (M.M. Dillon Ltd. 1995).

Figure 8.9
Trends in airborne arsenic levels at Yellowknife



Source: Environmental Technology Centre, Environment Canada.

Outlook

The discovery of diamond-bearing kimberlite pipes northeast of Yellowknife may result in new mining activity in that region. However, there is a lack of information on the ecology of the area. Consequently, a multistakeholder study — the West Kitikmeot/Slave Study — is under way to develop an information base in support of sound resource management decisions. Partners in the study include industry, Aboriginal organizations and communities, comanagement organizations established through land claims, other nongovernmental organizations, and federal and territorial government agencies. At Voisey's Bay, Labrador, baseline environmental information is being gathered by the proponent and government as part of the environmental review and permit process.

In 1989, Esso, Shell, and Gulf received approval to ship, between 1996 and 2016, some 260 billion cubic metres of gas from the Mackenzie Delta to the United States

via a major gas pipeline that would probably tie into existing pipelines at Zama, Alberta. As of early 1996, the project was on hold, considered not economically viable. Should a decision be made to go ahead, the project will be subject to a review by regulatory authorities, including examination of related environmental and social impacts.

The long-range transport of contaminants

Background
Research over the past few years, notably that conducted under the Arctic Environmental Strategy (see Chapter 9), has revealed the presence of unexpectedly high levels of various contaminants in northern Canada, both in the physical environment and in food webs (Lockhart 1995; Mackay and Wania 1995; Muir et al. 1996). This is of particular concern because of the quantities of country foods that are consumed by many people in the Taiga and Arctic. Hunting, fishing, trapping, and gathering sustained the ancestors of the ecozones' Inuvialuit, Dene (Gwich'in, Dogrib, Slavey), Cree, Inuit, and Innu (Montagnais, Naskapi) for thousands of years. Today, Indigenous peoples still obtain much of their food directly from the land.

The nature, levels, and fate of contaminants in the Taiga are particularly affected by the following factors:

- local geology and soils, which can be a source of metals such as mercury and cadmium (Geological Survey of Canada 1995; Rasmussen 1996);
- the flooding of vegetated land behind hydro dams, which, as previously mentioned, has resulted in the transformation of mercury into toxic methylmercury;
- general patterns of air circulation, which carry contaminants into sub-Arctic and Arctic areas;
- the contaminant-retaining properties of lichens, a major component of the diet of Caribou;
- the sub-Arctic climate, in which growth and decay occur more slowly than in temperate regions; and
- the tendency for organochlorines to accumulate in fatty tissues of long-lived species, notably marine mammals.

Organochlorine contaminants
High levels of organochlorine contaminants, such as polychlorinated biphenyls (PCBs), toxaphene, and dichlorodiphenyltrichloroethane (DDT), can cause various disorders in fish and other wildlife, as they have, for example, in the Great Lakes region (see Chapter 6). Although the use of PCBs and the DDT group of pesticides largely stopped in the Western world in the 1970s, their use continues in some developing countries. In addition, these contaminants can take decades, or even centuries, to break down. As organochlorines accumulate in animal fat, people who consume high levels of fatty tissue of species at the top of food webs are at greater risk of accumulating organochlorines. Polar Bear tissue and seal blubber contain PCBs and DDT, in particular, and walrus blubber from eastern Hudson Bay also contains PCBs. There has been little use of organochlorines in the Taiga, and thus the presence of these substances in the area's biota is evidence of long-range transport.

Table 8.9 provides a summary of findings on organochlorine contamination of fish within the Taiga. With one exception, in all cases where toxaphene was measured, it was present in higher concentrations than PCBs, which, in turn, were more prevalent than the sum of DDT-related compounds and total chlordane. In the majority of cases, analyses were done on muscle tissue. Considerably higher concentrations were found in liver tissue of Burbot. Livers of few other fish species have been analyzed. On a whole-fish basis, burbot and lake trout have similar contaminant levels.

Particularly high levels of toxaphene were detected in livers of Burbot from the Slave River, and Health Canada has recommended limiting consumption of Burbot livers from these waters (DIAND 1996). For any individual species, variations in organochlorine contaminant levels from one location to another are attributable to factors such as dietary differences and a tendency for contaminant concentrations to increase from north to south. Also, there tends to be a positive correlation between fish size and level of contamination.

By way of comparison, whereas PCB levels in Lake Trout at Taiga sites were generally less than 50 ppb, levels in the same species in the Canadian Great Lakes ranged from about 500 ppb in Lake Superior to about 2 000 ppb in Lake Ontario during the early 1990s (see Chapter 6). Similarly, for toxaphene, levels in Lake Trout in the Taiga have generally ranged between 10 and 100 ppb, compared with levels as high as 1 900 ppb in Lake Michigan in 1990 (De Vault et al. 1995).

Among mammals, mink eat from both terrestrial and aquatic food webs (small mammals and fish). This makes them particularly susceptible to contaminants in the food web and therefore a good indicator of such contaminants. A study of Mackenzie Valley mink found a distinct trend of increasing organochlorine contaminant burdens with decreasing latitude: mean total PCB residues ranged from 5.32 ppb wet weight in the livers of Inuvik area mink to 27.67 ppb in mink from the Fort Smith area. Dietary differences were not thought to be a significant contributing factor in the trend (Poole et al. 1995). These levels are low in comparison with those found in more southerly areas. For example, total PCB levels averaging 390 ppb and ranging from 34 to 1 797 ppb have been found in the livers of mink in southern Ontario (Muir et al. 1996).

A study of a range of contaminants in Caribou found that, in general, organochlorine residues, including PCBs, were significantly lower in Caribou from the mainland Bathurst and Qamanirjuaq herds than in Caribou from southern Baffin Island. Higher levels in the east were attributed to differences in atmospheric transport pathways (Elkin and Bethke 1995).

Very little long-term information is available on organochlorine contaminants in

the North. Although trend data exist for Arctic marine mammals, there is comparatively little information available for freshwater and terrestrial species (Muir et al. 1996). However, declining concentrations of toxaphene and other organochlorines have been noted in the livers of Burbot taken from the Mackenzie River at Fort Good Hope.

Heavy metals

Heavy metals include mercury, cadmium, copper, nickel, zinc, lead, and arsenic. The following sections focus on mercury and cadmium. Mercury is the one metal that has consistently exceeded guidelines for consumption or commercial sale of fish in the North. Cadmium has been the most prominent heavy metal contaminant in Caribou and other terrestrial mammals in the Taiga.

Mercury

The bioaccumulative characteristics and toxic effects of mercury are well recognized. The edge of the Canadian Shield in the southern Northwest Territories is known to be an area of relatively high natural mercury presence. Elevated levels have been measured, for example, around Great Bear Lake and Great Slave Lake, N.W.T., and Lake Athabasca, Alberta (Cameron and Jonasson 1972). Anthropogenic sources of mercury include fossil fuel combustion, the burning of waste, and the use of certain pesticides. Mention has already been made of the transformation of inorganic forms of mercury into methylmercury in reservoirs.

There has been extensive sampling of mercury in commercial species of fish in Canada since 1970. As a result, a number of lakes in the Northwest Territories and northern Quebec are known to have fish populations with mercury levels that exceed the 0.2 ppm guideline for subsistence consumption. Mercury levels in Lake Trout have frequently exceeded the 0.5 ppm guideline for commercial sale (Muir et al. 1996). In a three-year study of fish in the Hay River near Great Slave Lake, average mercury concentrations of 0.32, 0.22, and 0.07 ppm were recorded in Northern Pike, Walleye, and Lake

Table 8.9

Mean concentrations of some organochlorines in freshwater fish

Species	Lake/river	Region	Year	Tissue[a]	Concentration (ppb wet weight): Total DDT-related compounds	Total PCBs	Toxaphene	Reference
Broad Whitefish	Campbell Lake	Mackenzie Delta	1992	M	1.01	2.17	5.03	Lockhart et al. (1993)
	Kugaluk River	Mackenzie Delta	1992	M	0.67	6.19	6.85	Lockhart et al. (1993)
	"L 100"	Mackenzie Delta	1992	M	4.76	8.73	37.60	Lockhart et al. (1993)
	Horseshoe Bend	Mackenzie River	1992	M	0.15	0.82	3.21	Lockhart et al. (1993)
	Travaillant Lake	Lower Mackenzie River	1992	M	0.31	1.86	4.30	Lockhart et al. (1993)
Burbot	Alexie Lake	Yellowknife	1993	L	13.60	26.90	40.50	Muir and Lockhart (1994)
	Great Slave Lake	East and west basins	1993–1994	L	38.20	106.00	367.00	Muir and Lockhart (1994)
	Great Slave Lake	Fort Resolution	1994	M	0.40	1.94	2.15	Evans (1994)
	Mackenzie River	Fort Good Hope	1994	L	39.60	56.60	169.00	Muir and Lockhart (1994); Evans (1994)
	Trout Lake	Fort Simpson	1990	L	19.80	51 60	93 20	Muir and Lockhart (1994)
Lake Trout	Belot Lake	Colville	1992	M	20.00	44.10	115.00	Muir and Lockhart (1994)
	Colville Lake	Colville	1992	M	2.46	8.92	10.20	Muir and Lockhart (1994)
	Gordon Lake	Yellowknife	1990	M	5.35	16.30	23.10	Muir and Lockhart (1994)
	Great Slave Lake	East and west basins	1993–1994	M	7.69	23.90	94.40	Muir and Lockhart (1994); Evans (1994)
	Travaillant Lake	Lower Mackenzie River	1993	M	2.03	8.79	17.10	Lockhart et al. (1993)
	Trout Lake	Fort Simpson	1990	M	3.83	11.20	17.20	Muir and Lockhart (1994)
	Lac Bienville	Grande-Baleine	1989	M	6.68	47.10	–	Hydro-Québec (1993c)
	Lac Bienville	Grande-Baleine	1989	L	174.00	898.00	–	Hydro-Québec (1993c)
	Lac Raraire	Grande-Baleine	1989	M	<5.00	<15.00	–	Hydro-Québec (1993c)
	Lac Morpain	Grande-Baleine	1989	M	6 69	34.70	–	Hydro-Québec (1993c)
	Lac des Loups Marins	Grande-Baleine	1989	M	5.60	28.90	–	Hydro-Québec (1993c)
	Lac Amichinatwayach	Grande-Baleine	1989	M	<5.00	<15.00	–	Hydro-Québec (1993c)
Lake Whitefish	Colville Lake	Colville	1992	M	1.71	4.44	11.00	Muir and Lockhart (1994)
	Gordon Lake	Yellowknife	1990	M	3.72	7.94	13.90	Muir and Lockhart (1994)
	Great Slave Lake	East and west basins	1993–1994	M	8.31	22.20	104.00	Muir and Lockhart (1994); Evans (1994)
	Grande-Baleine lakes	Grande-Baleine	1989	M	<5.00	<15.00	–	Hydro-Québec (1993c)
Northern Pike	Lac Bienville	Grande-Baleine	1989	M	<5.00	<15.00	–	Hydro-Québec (1993c)
	Lac Morpain	Grande-Baleine	1989	M	<5.00	<15.00	–	Hydro-Québec (1993c)
Cisco	Great Slave Lake	Hay River	1994	M	4.11	12.90	77.40	Evans (1994)
Walleye	Hay River	Hay River	1994	M	0.61	1.40	0.40	Muir and Lockhart (1994)

[a] M = muscle plus skin; L = liver.

Source: Adapted from Muir et al. (1996).

Whitefish, respectively (Table 8.10). Almost 90% of the total mercury content was methylmercury. Based on the combined results from the Hay River site and two other sites in the vicinity of Fort Smith, it was concluded that geology and atmospheric transport, not local human activity, were the likely sources of mercury in the study area (Grey et al. 1995).

In the Mackenzie Valley, moderate levels of mercury (means of 1.16–3.30 ppm wet weight in livers at five study sites) were recorded in 109 mink sampled between 1991 and 1993 (Poole et al. 1995). Levels of mercury in northern mink are the lowest for this species in North America and, unlike levels in the Great Lakes area, are probably too low to affect mink reproduction or population health (DIAND 1996). Levels of potentially toxic metals other than mercury in the kidneys of Mackenzie Valley mink were also low (Poole et al. 1995).

Lake sediment cores have been analyzed for mercury at several sites, primarily in the Northwest Territories and Yukon, to see if there have been any trends in the amount of the substance reaching the lakes. Through isotopic dating of sediment layers, researchers have determined that mercury input to sampled lakes in the eastern Northwest Territories has generally been increasing since at least 1850, if not earlier. The primary mechanism behind the increase is thought to be atmospheric transport of mercury from human-related sources, although natural processes could also be responsible. In the western Northwest Territories and Yukon, where mercury enrichment from natural sources is greater than in the eastern Northwest Territories, it has been difficult to discern human-related trends in mercury levels (Lockhart et al. 1995). The relative contributions of local natural sources of mercury and distant natural and anthropogenic sources are not well understood and require further investigation.

Cadmium

Cadmium, another naturally occurring element, accumulates in tissues of several species, including Caribou. At sufficiently high levels, it can cause liver and kidney disorders. Like mercury and other metals, it occurs naturally in significant and highly variable amounts. Naturally occurring cadmium enters the food chain through physical and chemical weathering of bedrock and till. Other natural sources include volcanic eruptions and windblown dust. Cadmium is used in the manufacture of items such as batteries, paints, and plastics. Natural levels can be enhanced through activities such as the burning of fossil fuels and waste materials at facilities that do not have proper emission control technologies. Cigarette smoke is a key source of cadmium for humans.

Elkin and Bethke (1995) sampled for a wide range of contaminants in Caribou from five herds across the southern Canadian Arctic, including Bathurst and Qamanirjuaq Caribou, which winter in the Taiga. Other herds sampled were on Southampton and southern Baffin islands. Relatively low levels of metals were found, with the exception of cadmium and mercury. The primary source of cadmium affecting Caribou is lichens, a staple item of their winter diet. Cadmium was moderately elevated in both kidney and liver tissue, particularly the former. Concentrations were similar to those found in Caribou from northern Quebec and in Norwegian reindeer. Highest concentrations in kidney tissue were measured in Qamanirjuaq Caribou, and the lowest levels were found in Bathurst Caribou. Although the cadmium contamination varied significantly from one location to another, it showed no apparent north–south or east–west trend.

Caribou on the other side of Hudson Bay in the eastern Taiga Shield ecozone are also accumulating cadmium. Crête et al. (1989) measured cadmium levels in kidney, liver, skeletal muscle, mesentery, and rumen wall tissues of Caribou from the George River herd in the Quebec portion of the Taiga Shield ecozone in 1985–1986. They recorded higher levels in kidneys, liver, and skeletal muscles in winter than in autumn, probably reflecting the fact that the Caribou sampled ate more lichens in winter than during the rest of the year. They determined that a person eating 250 g of Caribou kidney would take in 3 000 μg of cadmium; a similar serving of liver

Table 8.10
Mean concentrations of metals in the muscle tissue of freshwater fish

Species	Location	Year	Concentration (ppb or ppm wet weight) Cadmium (ppb)	Copper (ppm)	Zinc (ppm)	Mercury (ppm)	Selenium (ppm)	Reference
Lake Trout	Colville Lake, N.W.T.	1993	0.9	1.21	3.08	0.28	0.17	Muir and Lockhart (1994)
	Grande-Baleine, Que.	1989–1990	10.0	0.35	3.28	0.71	0.79	Hydro-Québec (1993c)
Lake Whitefish	Colville Lake, N.W.T.	1992	1.0	1.07	3.07	0.02	0.14	Muir and Lockhart (1994)
	Hay River, N.W.T.	1988–1990	–	–	–	0.07	–	Grey et al. (1995)
	Grande-Baleine, Que.	1989–1990	<20.0	0.38	4.00	0.14	0.66	Hydro-Québec (1993c)
Northern Pike	Grande-Baleine, Que.	1989–1990	<50.0	0.27	3.80	0.63	0.58	Hydro-Québec (1993c)
	Hay River, N.W.T.	1988–1990	–	–	–	0.32	–	Grey et al. (1995)
Walleye	Hay River, N.W.T.	1988–1990	–	–	–	0.22	–	Grey et al. (1995)

would deliver 240 μg of cadmium. The World Health Organization has established a provisional tolerable weekly intake of 7.0 μg of cadmium for each kilogram of body weight. Occasional intake above this amount can be tolerated, provided the situation is not prolonged (WHO 1989). Residents of the Taiga Shield ecozone in Labrador, Quebec, and the Northwest Territories have therefore been advised to reduce their consumption of Caribou kidneys and livers, although there is no restriction on consumption of other Caribou tissues (Archibald and Kosatsky 1991; Newfoundland and Labrador Department of Natural Resources 1995; DIAND 1996).

Radionuclides

The testing of nuclear devices in the atmosphere from 1955 until the moratorium on such testing in 1963 resulted in the widespread deposition of various radioisotope fission products. The radioactive fallout was especially heavy between 40°N and 50°N latitude, as most testing took place at northern temperate and subtropical locations. Concerns over potential human health effects have led to numerous investigations into the fate of these contaminants, especially cesium-137. Of particular concern in the Taiga and Arctic is the accumulation of radionuclides in lichens and the transmission of those contaminants to humans through the lichen–Caribou–human food chain. Lichens accumulate radionuclides more than many other plants partly because of their long life span and large surface area. Lichens are a main food source for Caribou during the winter season, and cesium concentrates mainly in the animals' muscle tissue.

From 1962 to 1966, cesium-137 levels were monitored in Caribou muscle tissue across northern Canada. Mean levels ranged from 400 Bq/kg of wet tissue for Caribou near Pond Inlet, Baffin Island, to 2 000 Bq/kg for Caribou from the Bathurst herd near Yellowknife (Thomas et al. 1992). Levels of up to 300 Bq/kg are considered safe for human consumption (Crête et al. 1987, cited in Thomas et al. 1992). Approximately two decades later, between 1986 and 1988, and following the explosion and fire at the Chernobyl Nuclear Power Station in the former Soviet Union, Health and Welfare Canada studied the levels of cesium-137 in Caribou across the Arctic and Taiga. The mean value for Bathurst herd Caribou had fallen to 460 Bq/kg. In the Taiga, the most heavily contaminated Caribou sampled were from the Caniapiscau region of the eastern Taiga Shield ecozone. A person eating 700 g of that meat per day would receive at most 3.59 mSv (millisieverts) of radiation per year, which is less than the approved limit of 5 mSv per year (Marshall and Tracy 1989). Average annual exposure in Canada is 2 mSv; a whole-mouth dental x-ray provides 0.2 mSv.

Effects on people

A program to sample maternal and placental-cord blood of women giving birth at Stanton Yellowknife Hospital was undertaken in 1994–1995, to determine levels of mercury, cadmium, lead, and PCBs in the mothers and their infants (Government of the Northwest Territories 1995b). In all cases, the measured contaminant levels were below thresholds at which health problems may begin. In the late 1980s, PCB levels in breast milk from women in northern and southern Quebec were compared (Dewailly et al. 1989). PCB concentrations in the milk fat of Inuit women from northern Quebec were found to be almost five times those for Caucasian women from southern Quebec — a highly significant result. Concern over these findings led to additional studies, and no conclusive evidence of health risk associated with the consumption of country food was found (see Chapter 9).

Climate change

Most climate modelling experiments suggest that, in the event of a continued enhancement of the greenhouse effect, air temperatures would rise over most of Canada, with the greatest warming occurring in the interior continental part of the nation (see Chapters 10 and 15 for more in-depth discussion of the climate change issue). Results from a model developed by the Atmospheric Environment Service of Environment Canada suggest that if current trends continue, average air temperatures across the Taiga could rise 2–4°C in summer and as much as 10°C in winter within the next 100 years (Hengeveld 1995). Considering the severity of winter in the Taiga, that might not seem like such a bad thing. Certain types of agriculture might become feasible in areas that are currently marginal in capability. The same could hold true for forestry. Transportation on inland waterways, particularly the Mackenzie River, would benefit from a longer period of open water. A shorter ice season on Hudson Bay would allow for a longer shipping season out of the port of Churchill. Tourism would probably benefit from a longer summer.

However, a warming of this order would precipitate major disruptions in Taiga ecosystems. Some permafrost would thaw; the duration and characteristics of snow cover would change; wildfires could consume more forest; terrestrial, wetland, and aquatic habitats would change; and wildlife distributions and communities would be altered (Pruitt 1993). Because one-quarter of the world's storehouse of soil carbon is in boreal and wetland ecosystems, the response of Taiga ecosystems to greenhouse effect warming could be a critical element in determining further climate change (Box 8.5).

Permafrost throughout much of the Taiga is close to the melting point, and thus it would not require a lot of warming to precipitate its degradation. From the standpoint of the integrity of infrastructure, the warming or even disappearance of permafrost in areas of low or negligible ground ice poses little or no risk. However, where ice-rich permafrost exists, as it does in the lower Mackenzie Valley, for instance, the decay of permafrost could have serious repercussions. Thermokarst subsidence and erosion could jeopardize the integrity of facilities such as the Norman Wells pipeline and the Dempster Highway. Increased soil erosion could cause higher sediment loadings in lakes and rivers, altering the quality of aquatic habitat.

Climate change could have serious implications for wildlife. Climate-related con-

Box 8.5
The Canadian Northern Wetlands Study

In 1988, Canadian scientists initiated an international multiagency study to investigate the role of northern wetlands as sources and sinks of greenhouse gases. Research sites were established within the Hudson Plains ecozone, and a shorter-term study was carried out at Schefferville, Quebec, to allow for a comparison of greenhouse gas exchanges in the Hudson Bay wetlands with those over continental interior ecosystems. A baseline air chemistry monitoring station was also set up at Fraserdale, which is south of Moosonee and just south of the Hudson Plains ecozone.

The Hudson Plains ecozone is characterized by a progression of wetland types. These range from saltwater and brackish marshes on the tidal flats of Hudson and James bays through vast freshwater marshes (shallow, emergent grasses and sedges), treed and ribbed fens (rich peatlands fed by slow-moving groundwater), and raised bogs (acid peatlands fed only by rainwater). There are also isolated upland areas consisting of ancient beach ridges, occasional bedrock outcrops, and river levees. In general, the depth of the peat increases from the coast to the interior, with depths reaching 2–3 m. The peat results from the buildup of partially decomposed vegetation between the living vegetation layer and the soil. Carbon, from carbon dioxide, is assimilated into the vegetation and subsequently retained in the peat. Given its extent, the Hudson Plains ecozone contains an enormous accumulation of peat and therefore represents an important sink of carbon.

At the same time, wetlands are the most significant "natural" source of methane (an important greenhouse gas) to the atmosphere. As subsurface peat decomposes in wetlands under anaerobic conditions, methane gas is commonly released. In general, the study found that the release of methane from the Hudson Plains ecozone increased from marshes to fens to bogs, which is consistent with the increasing depth and age of the peat. Ponds, which cover 8–12% of the Hudson Plains ecozone, account for about 30% of the methane released to the atmosphere. Measurements from the study have also revealed that methane emissions from Hudson Bay lowland wetlands are 5–15 times lower than previously estimated (Glooschenko et al. 1994).

Under various climate change scenarios, significant changes are expected in the Hudson Plains ecozone's temperature, precipitation, and permafrost conditions. Climate change could affect and alter landscape characteristics of the region (e.g., wetland extent and characteristics), which, in turn, would alter the role of the region as a source or sink of greenhouse gases.

siderations in Caribou health and survival, for example, include the following (Gunn 1995):

- the weather during the growing season, which influences winter forage availability;
- snow conditions, such as depth and density, which affect foraging success in winter and also mobility of both the Caribou and its key predator, the Wolf;
- the timing of lake and river ice freeze-up and breakup, which can be critical for migrating Caribou because of the danger associated with travel over thin or rotten ice; and
- summer weather conditions, such as air temperature and wind speed, which influence biting insect activity and therefore the level of harassment for Caribou.

Weather and climate play a significant role in the life of Caribou, and any alterations would have a bearing on the well-being of the animals. Gunn (1995) concluded that "the most likely outcome of a warmer climate will be a decline in caribou and musk-oxen, particularly if there is a greater frequency and amplitude of weather extremes."

The issue of climate change has sparked a major multidisciplinary study in the Mackenzie basin (Box 8.6). The basin contains a variety of ecosystem boundaries sensitive to climate, such as the tree line and the southern extent of continuous permafrost, as well as resources that are important to both the traditional economy and the cash economy of the Northwest Territories (Environment Canada 1994c).

The Road to Environmental Sustainability

As Chapter 16 points out, the concept of sustainable development has evolved over time. The environmental goals of sustainable development as expressed in the report of the Brundtland Commission (World Commission on Environment and Development 1987) were derived, for example, from the objectives of the World Conservation Strategy (IUCN 1980). Those objectives — the maintenance of essential ecological processes and life support systems, the preservation of biological diversity, and the sustainable use of species and ecosystems — are the basic criteria used to assess whether human activities are environmentally sustainable.

Several initiatives that relate to environmental sustainability in the Taiga have already been mentioned in the course of this chapter, among them the Arctic Environmental Strategy, the Canadian Northern Wetlands Study, the Mackenzie Basin Impact Study, and several land claims agreements. Many other initiatives exist, the following being but a few of them.

Management responses towards sustainability

Hydroelectric development

In 1986, the James Bay Cree, Hydro-Québec, and the Quebec government signed the James Bay Mercury Agreement. The operation of the 1986 James Bay Mercury Agreement has shown how increased mercury levels in fish due to reservoir creation can be managed to prevent health risks, while maintaining the traditional way of life of Aboriginal people. The agree-

ment entails monitoring mercury levels in fish, monitoring Cree exposure to mercury, information strategies aimed at the Cree, and incentives to promote the harvesting of non-fish-eating fish and of alternative bush food with low mercury levels (James Bay Mercury Committee 1995; Sbeghen and Schetagne 1995).

Mining and hydrocarbon production

The Whitehorse Mining Initiative is an agenda for the sustainable development of the mining industry in Canada. Contributors to the initiative represent a broad range of stakeholders: industry, governments, labour, Aboriginals, and environmental organizations. Aspects being addressed include the establishment of protected areas, Aboriginal land claims, and environmental protection (see the "Minerals, metals, and mining" component of Chapter 11).

Cleanup associated with acid mine drainage is regarded as the most significant environmental problem facing the Canadian mining industry today. In recognition of this, the mining industry, the federal government, and eight provincial governments have collaborated in developing the Mine Environmental Neutral Drainage (MEND) Program. MEND, which began in 1989, is focusing on the development of new technologies to deal with acid mine drainage and on the provision of information to those requiring it. (Additional details on MEND are provided in Chapter 11.)

New mine approvals require companies to plan for decommissioning when mines are designed. Reclamation has become an integral part of planning for new operations. Existing mines are required to file detailed reclamation plans for approval, to provide financial assurance that their site will be decommissioned in accordance with approved plans, and to ensure that

Box 8.6
The Mackenzie Basin Impact Study

The Mackenzie Basin Impact Study (MBIS) aims to assess the potential effects of global warming on the basin and its inhabitants. Most climate change scenarios suggest that northwestern mainland Canada would experience greater warming than much of the rest of the country (see Chapters 10 and 15). Warming as high as 1.8°C has been observed in the Mackenzie basin over the past century.

The MBIS is a six-year study that began in 1990. One of the first attempts at an integrated regional assessment of climate change, it includes participants from federal, provincial, and territorial governments, academia, the energy industry, and Aboriginal communities. The scope of the study encompasses interjurisdictional water management, the sustainability of traditional ways of life, economic development opportunities, the sustainability of ecosystems, and issues related to buildings, transportation, and infrastructure. Following are some of the points made at workshops held in Yellowknife in 1994 and 1996 to share results (Cohen 1995, 1996):

- *Higher mean annual temperature and precipitation might be more than offset by increased evapotranspiration. The consequent decrease in runoff might lead to reductions in water levels at Great Slave and Great Bear lakes. In the Boreal Plains ecozone to the south of the Taiga, the duration of winter ice cover on the Peace River might be shortened by warmer temperatures, but that could be offset by reductions in river flow or changes in discharge from the Bennett Dam.*
- *Permafrost could be expected to retreat northwards — indeed, there have already been landslides related to melting permafrost within the Mackenzie Valley — but this would vary considerably from site to site. Sites that are well insulated by sphagnum mosses tend to remain frozen, despite some surface warming. Along the coast of the Beaufort Sea, coastal recession could accelerate, owing to increased storm surges.*
- *Scenarios of probable forest fire risk range from a modest decrease in risk to an increase in burned area of 40–81%. Results point to large increases in the fire weather index (a measure of weather-related fire hazard). Increased fire frequency, fire severity, and fire season length could lead to a reduction in average tree age with a corresponding reduction in forest yield, despite the increased productivity of trees in a warmer climate.*
- *Land capability for agriculture could improve owing to lengthening of the growing season, but there would be decreases in soil moisture supply. However, crop varieties used in southern Canada could produce lower yields in northern latitudes because of differences in climatic characteristics such as day length during the growing season. Improvements in crop yield would be dependent upon the development of species better suited to high-latitude conditions.*
- *The combination of potential environmental changes associated with climate change could prove detrimental to the Bathurst Caribou herd of the eastern Taiga Plains ecozone (see Fig. 8.3). A decline in the size of the herd would have negative consequences for both sport and traditional hunters.*

Even if a complete inventory of effects could be described with certainty, important questions would remain. Faced with a scenario of changing resource capabilities, what would be the implications for current resources and their users, many of whom are Aboriginal? What would be the effect on harvesting, on Aboriginal lifestyles, and on land claim agreements and associated policy instruments that have been established to guarantee harvesting rights? This scenario of the effects of climate change may present a different vision of the future than that held by most stakeholders in the Taiga. Thus, these types of questions need to be addressed by all parties concerned with the region's natural resources and the communities that depend on them. They relate not only to regional-scale adaptation measures to climate change, but also to national and international efforts to reduce greenhouse gas emissions.

funds are available to fully reclaim the property in accordance with the reclamation plan (Box 8.7).

The long-range transport of contaminants

The United Nations Convention on Long-Range Transboundary Air Pollution dates back to 1979. Canada signed the original Convention in 1979 and has also signed subsequent protocols that address emissions of sulphur dioxide and nitrogen oxides. Canada is participating in the development of a protocol on persistent organic pollutants and the negotiation of a protocol on heavy metals under the Convention.

Canada is also leading work to address the global persistent organic pollutants problem under the United Nations Environment Programme.

Climate change

At the international level, the United Nations Framework Convention on Climate Change was signed by more than 150 nations at the 1992 United Nations Conference on Environment and Development. The ultimate goal of the convention is the stabilization of atmospheric greenhouse gas concentrations at a level that would prevent dangerous human-related interference with the climate system. Canada has made an initial commitment under the convention to stabilize net greenhouse gas emissions (other than those covered by the Montreal Protocol) at 1990 levels by the year 2000. Canada's National Action Program on Climate Change (CCME 1995) presents a range of largely voluntary measures for achieving the stabilization of greenhouse gas emissions (see Chapter 15). A key element of the program is the Voluntary Challenge and Registry, which invites Canadian companies and organizations to develop and pursue action plans to limit net greenhouse gas emissions.

Renewable resource conservation and protection

Various national and international measures to address the conservation and protection of wildlife are discussed in Chapters 10 and 14 (e.g., the Canadian

Box 8.7
Decommissioning the Pine Point mine

Detailed abandonment activities and postclosure monitoring have been carried out at the Pine Point mine, which is located just outside the Taiga Plains ecozone on the south side of Great Slave Lake, about 80 km east of Hay River. The decommissioning of this open-pit mine illustrates that, with good planning, such operations can be successfully decommissioned in a sub-Arctic environment.

Cominco Ltd. operated a zinc–lead mine on the property (65 km long and 24 km wide) from 1964 to 1988. During this time, 82 million tonnes of tailings were generated. The company produced a formal restoration and abandonment plan for the site in June 1987. This plan has been periodically updated since the decommissioning activities began in 1988. Mining activities ceased in 1987, at which time the mill continued to process the approximately 2 million tonnes of stockpiled lead and zinc ore stored on gravel pads at the site. By spring 1991, all of the stockpiled ore had been milled, and the resulting concentrates had been shipped south.

The major disturbed areas left after the stockpiles of ore and lead and zinc concentrates had been exhausted were (1) 47 open pits; (2) a 570-ha tailings containment area; (3) waste rock dumps; (4) buildings; (5) the gravel pads on which the concentrate had been stockpiled; (6) service trenches, including water intake facilities; (7) scrap equipment and garbage; and (8) a rail line built to service the mine. The closure plan provided for the removal of all of the structures and the filling and grading of all remaining basements or disturbances; the recontouring of the containment area, such that it is flatter and has more stable slopes that minimize the potential for erosion; and the covering of the containment area with a stable surface to protect it from wind erosion. The plan also provided for the monitoring of the stability of the dike that surrounds the tailings, the construction of a permanent spillway through the dike to discharge runoff, and the treatment of that effluent until it consistently meets Water Licence requirements.

All buildings have been removed from the site. The concentrate stockpile pads have been treated to recover sulphide, which was shipped outside the Northwest Territories for further treatment. The remaining portions of the pads have been disposed of in the tailings pond. Waste oil that was stored in tanks has been removed for treatment and recycling.

The rail line has been removed by the railway company, and all bridges and culverts were removed from the rail right-of-way. Open pits closest to the public roads have been fenced and bermed. All other pits have been bermed to prevent inadvertent access. In areas with an elevated water table, pits have been allowed to fill with water.

Currently, the principal concern is the tailings area. Elevated levels of zinc still occur in the runoff water that flushes the tailings and collects inside the dike. The tailings have a low sulphide content and are considered to have "low" potential for acid generation (DIAND 1994c). The water in the tailings pond is treated with lime prior to discharge to lower the zinc content to comply with Water Licence effluent requirements. By 1992, about 80% of the pond had dried out and was covered with a layer of coarse gravel to stabilize the surface and prevent emissions of dust during windy periods. The waste rock dumps, which have "low" potential for acid mine drainage (DIAND 1994c), have been contoured, and some have been covered with till and seeded. The garbage dump, located in an old open pit, has been buried with a layer of fill.

Reclamation was completed with the removal of the dragline in 1995. Treatment of tailings pond water prior to discharge is continuing. The situation will be assessed each year, and treatment will be carried out as necessary. The existing Water Licence expires in 1998.

Biodiversity Strategy, Recovery of Nationally Endangered Wildlife, the United Nations Framework Convention on Biological Diversity, and the Convention on International Trade in Endangered Species of Wild Fauna and Flora).

The Government of the Northwest Territories has developed a Strategy for Renewable Resource Development that covers wildlife, forests, and agriculture. The underlying philosophy is that renewable resources will be used "to pursue broader government objectives of enhancing community self-sufficiency and contributing to local economies while maintaining biological diversity and environmental integrity" (Government of the Northwest Territories 1994b). The strategy aims to "protect and enhance the quality of the environment," "manage and develop renewable resources on a sustainable basis to benefit present and future generations of northerners," and manage the resources through "public input and scientific and indigenous knowledge."

A perceived crisis in herd populations gave rise in the early 1980s to the oldest natural resource comanagement arrangement in Canada for a major game species, the Beverly–Qamanirjuaq Caribou Management Board (Usher 1995) (Box 8.8). New management mechanisms are resulting from comanagement clauses in Aboriginal land claim agreements (see Box 8.1) and other partnership agreements. These new approaches give increased authority to Aboriginals who live in the Taiga and promote the exchange of ideas between scientific researchers and hunters.

Support for community-based management initiatives in the Northwest Territories has been available from the Department of Indian Affairs and Northern Development under the Northwest Territories Community Resource Management Program, one component of the Arctic Environmental Strategy. The committees that selected proposals for funding comprised representatives of Aboriginal groups, various levels of government, and scientific institutions.

All species require some form of habitat to survive. As elsewhere in Canada, various types of protected areas have been established in the Taiga for purposes that include habitat conservation and the protection of wildlife. As of late 1995, approximately 4.4, 3.2, and 19.1% of land in the Taiga Plains, Taiga Shield, and Hudson Plains ecozones, respectively, was designated as protected to at least some degree. A subset of more highly protected areas — namely, nature reserves, wilderness areas, national parks (or their equivalent), and natural monuments — provides a greater level of security for wildlife and their habitat. These areas constituted 3.2, 0.9, and 7.5% of the three ecozones, respectively. Noteworthy examples within the latter category include Ramsar sites, which are wetlands of international importance. Of the 30 Ramsar sites in Canada, three are entirely within the Taiga: Hay–Zama Lakes in northwestern Alberta; Polar Bear Provincial Park adjacent to Hudson Bay in northern Ontario; and the Southern James Bay Migratory Bird Sanctuaries in northern Ontario near the Quebec border. Wapusk National Park is a recent addition to the protected area network in the Taiga. The park encompasses 11 475 km^2 of land bordering on Hudson Bay, south and east of Churchill, Manitoba. The area is home to one of the world's largest known Polar Bear denning sites.

Environmental information

Unless data are collected systematically over the long term, it is impossible to assess conditions and trends or, as experience has shown, to carry out meaningful project-specific or cumulative impact assessments. The Arctic Environmental Strategy, which began in 1991, and under which a considerable number of the con-

Box 8.8
The Beverly–Qamanirjuaq Caribou Management Board

Scientists believe that the combined Beverly and Qamanirjuaq Barren-ground Caribou herds (see Fig. 8.3), two of North America's largest concentrations of large mammals, once numbered in the millions. In 1982, a survey indicated that the Caribou herds were in a serious decline. Since that time, a combination of improved techniques for surveying and estimating population numbers and favourable natural conditions has resulted in much larger population estimates. In 1995, the Beverly herd was estimated to have between 175 000 and 397 000 Caribou, and the Qamanirjuaq herd between 390 600 and 601 400 Caribou (A. Gunn, Department of Renewable Resources, Government of the Northwest Territories, personal communication).

The Beverly–Qamanirjuaq Caribou Management Board was created in 1982 by the governments of Manitoba, Saskatchewan, the Northwest Territories, and Canada in response to a perceived crisis in the management of the two herds. Its objectives are to protect the two herds, to protect the ways of life of traditional Caribou users, to ensure cooperative joint management of Caribou by users and government management authorities, and to promote conservation through communication and education. The board has 13 members, 5 of whom represent government interests. The remaining eight members represent the Dene, Métis, and Inuit user groups, with two from each of Saskatchewan and Manitoba and four from the Northwest Territories.

The board makes recommendations to users and governments for the conservation of the two herds and sponsors research, including population surveys, collection of kill data from hunters, and radiotelemetry tracking of the movements of the herds. Information about herd movements is provided to local hunters' and trappers' associations on a regular basis. The board has developed and published a management plan for the two herds, recommendations for managing forest fires on the Caribou's treed winter ranges, as well as a variety of conservation education materials.

The mandate of the board, originally set to last 10 years, was extended in 1991 for another 10 years (Beverly–Qamanirjuaq Caribou Management Board 1993).

taminant data reported on in this chapter were collected, will terminate in 1997. Despite the monitoring conducted under the strategy, what are still generally lacking for northern Canada are long-term data that will enable a response to the question "Is it getting better or worse?"

In 1994, the First Nations of the Moose River Basin and the Government of Ontario established a baseline data collection project called the Environmental Information Partnership (Ontario Ministry of Natural Resources 1994). Its purpose is to collect and manage baseline data, in order to provide a foundation on which to assess the cumulative environmental impacts of development within the Moose River basin. Significantly, traditional ecological knowledge is treated as equal to other forms of knowledge. Data collection will respond to the values expressed by basin stakeholders, and information will be made available to assist in decision-making processes. The initiative was influenced by the Northern River Basins Study (see Chapter 4).

The Hudson Bay Program, run by the Canadian Arctic Resources Committee, the Rawson Academy of Aquatic Science, and the Environment Committee of the community of Sanikiluaq (on the Belcher Islands), is attempting to assess the cumulative effects of development on Hudson Bay and to devise a sustainable development strategy for Hudson Bay. In the first phase of the program, traditional knowledge and the relevant science are being gathered and integrated.

The Labrador Ecosystems Analysis Facility (LEAF) is being designed to research the ecosystems and natural resources of Labrador, incorporate traditional ecological knowledge and databases into mainstream scientific thought, and promote the transfer of knowledge and technology to the peoples of Labrador (Task Force of the Labrador Ecosystems Analysis Facility 1992). Proposed activities include inventories of the distribution of wildlife, consistent and systematic collection of environmental baseline data, and special projects related to resources.

Conclusion

By southern Canadian standards, the Taiga is characterized by a generally low level of *internal* human activity. Agriculture is negligible, and forestry is confined to the southern Taiga Plains ecozone. There are few roads, and even fewer rail lines. However, three major hydroelectric developments affect parts of the Taiga Shield and Hudson Plains ecozones, several mines have been developed, notably in the western Taiga Shield ecozone, and a pipeline has been constructed to carry oil southward from Norman Wells. Yet even these developments have not directly affected a large part of the Taiga. Extensive subsistence, recreational, and commercial fishing, trapping, and hunting take place, but at controlled levels.

On the other hand, human activities *external* to the Taiga are affecting, or have the potential to affect, much, if not all, of the region. Airborne contaminants, particularly organochlorines, are reaching the Taiga and bioaccumulating in food chains. Human-induced climate change has the potential to alter key attributes of the Taiga environment, such as the distribution of permafrost, thereby changing habitat characteristics and disrupting various human activities.

The impact of human activities, both within and outside the Taiga, will affect the future sustainability of its ecosystems. The study of ecosystems, the control, mitigation, and monitoring of the effects of existing developments, and the levels of wildlife harvesting are each of paramount importance if current valuable ecological characteristics are to be maintained. This information will also be necessary for planning sustainable economic development within the Taiga, be it mining, hydro, petroleum, infrastructure, or commercial hunting.

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Chapter 9 Arctic Ecozones

Highlights

There are six Canadian Arctic ecozones: three terrestrial — Arctic Cordillera, Northern Arctic, and Southern Arctic; and three marine — Arctic Archipelago, Arctic Basin, and the northern portion of the Northwest Atlantic. They comprise all Canada's Arctic islands and seas (including all of Hudson and James bays), as well as most of the continent north of the tree line. These ecozones provide the Canadian Inuit with food and income; moreover, they are the basis of their society and culture.

■

The Canadian Arctic is no longer a pristine region. Contaminants from distant regions are deposited on land and water by atmospheric circulation. Contamination is also transported into Arctic marine waters by rivers and ocean currents. Arctic predators take in contaminants from prey animals, such as migratory birds that have picked up contaminants in distant locations.

■

To date, no recorded changes in the physiology, behaviour, or community structure of Arctic fish or wildlife have been associated with current contaminant levels. In humans, no significant clinical effects have been found, although preliminary results suggest that exposure to persistent organic pollutants may be associated with smaller newborn boys and reduced infant immunity.

■

Advances have been made in scientific understanding of northern ecology, in the integration of Indigenous knowledge with scientific knowledge, and in the involvement of local residents in resource management.

■

Some initiatives for sustainable development in the Arctic are under way at community, territorial, federal, and international levels. These include Aboriginal land claim agreements, including comanagement arrangements, the establishment of protected areas, the national Arctic Environmental Strategy, the circumpolar Arctic Environmental Protection Strategy, and the Inuit Circumpolar Conference.

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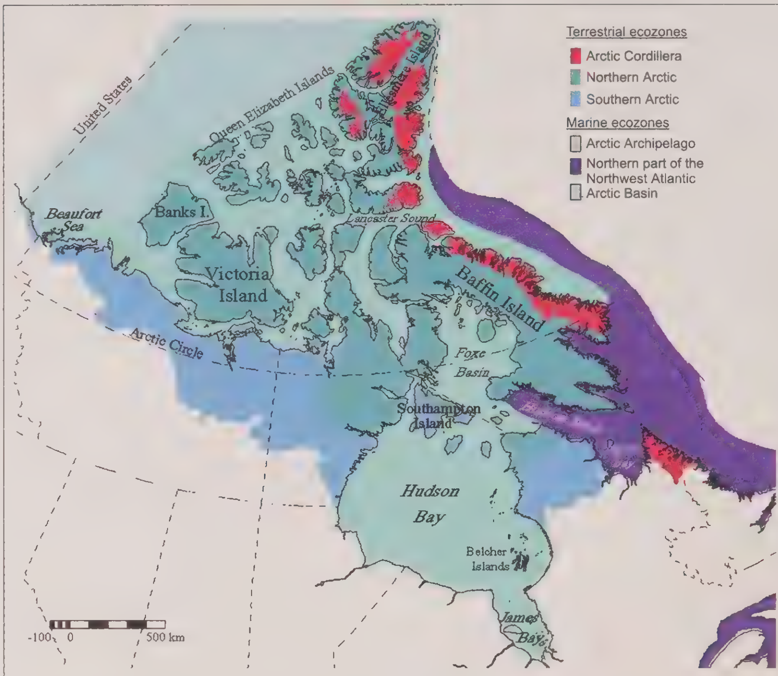
Introduction

The Canadian Arctic is not as pristine as might be expected, given its low population and lack of industrial development. Contamination has reached it from distant sources, largely through the atmosphere, but also in animal life, in ocean currents, and in rivers. Not all pollution arrives from afar, however. Increasing human activity in the Arctic ecozones (Fig. 9.1a) over the past several decades has brought local environmental impacts from resource development, waste disposal, military activities, tourism, and construction.

In this report, the Canadian Arctic comprises three terrestrial ecozones: Arctic Cordillera, Northern Arctic, and Southern Arctic; and three marine ecozones: Arctic Archipelago, Arctic Basin, and the northern portion of the Northwest Atlantic (Fig. 9.1a). It encompasses nearly a quarter of Canada's land area, a coastline longer than that of all of Canada's ocean-fronting provinces together, and most of Canada's continental shelf. The six ecozones comprise more than half of the Northwest Territories, a large piece of northern Quebec (Nunavik), and small portions of Yukon and Labrador (Newfoundland). The three terrestrial ecozones are all young ecosystems in geological terms. They feature continuous permafrost, distinct flora and fauna, limited nonrenewable resource development — despite high potential for such development — and a sparse, predominantly Inuit population, with a continuing strong reliance on hunting and fishing. The three marine ecozones are dominated by the presence of year-round or seasonal ice, which limits overall biological activity, although ecosystems at the ice edge can be rich feeding areas for mammals and birds.

From a southern Canadian standpoint, the Arctic has two seasons — a long winter and a very short summer. But from a northern Aboriginal perspective, there are six seasons. Aboriginal harvesting cycles

Figure 9.1a
Arctic ecozone boundaries



Source: State of the Environment Directorate, Environment Canada.

Figure 9.1b
Population change in selected centres, 1971–1991

	Population		
Selected centres	1971	1991	% change
Resolute, N.W.T.	184	171	–7
Sachs Harbour, N.W.T.	143	125	–13
Tuktoyaktuk, N.W.T.	596	918	54
Clyde River, N.W.T.	274	565	106
Klugluktuk, N.W.T.	637	1 059	66
Iqaluit, N.W.T.	2 014	3 552	76
Baker Lake, N.W.T.	756	1 186	57
Chesterfield Inlet, N.W.T.	258	316	22
Inukjuak, Quebec	525	1 044	99

Note: The geographic extent of a Census Metropolitan Area in 1971 may not correspond to that for 1991. For further details, see Endnotes.

Source: Special tabulations prepared by Statistics Canada. For further details, see Endnotes.

are intimately based on the complex and constantly changing state of snow and ice cover, water, and light (Fig. 9.2).

Canada's six Arctic ecozones form part of a much larger, circumpolar ecosystem (Fig. 9.3). The eight countries in the circumpolar region share responsibility for environmental stewardship and resource management.

Biophysical characteristics of terrestrial ecozones

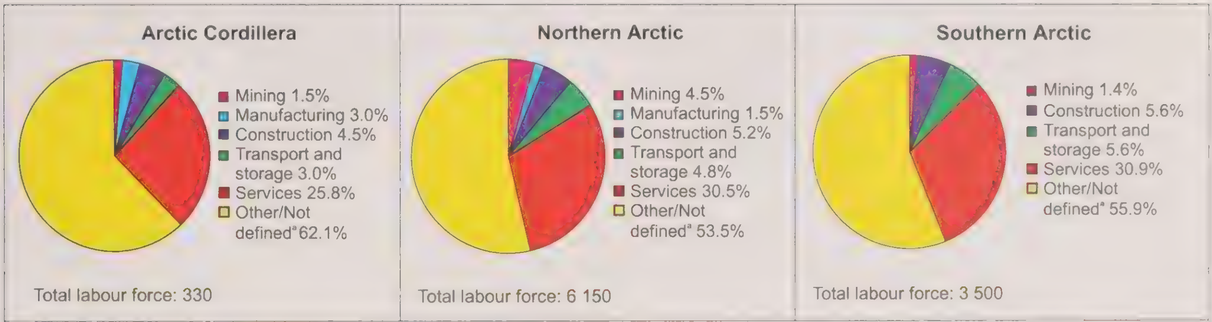
The Canadian Arctic's terrestrial ecozones (Fig. 9.1a) represent 25% of Canada's and 20% of the circumpolar Arctic's land area (Conservation of Arctic Flora and Fauna 1994; U.S. CIA 1994). The summer land cover ranges from Arctic tundra, with low plants and wetlands, to rocky, barren land, with extremely sparse or no vegetation. Some places are covered with snow and ice year-round (Fig. 9.1e).

Hydrological processes vary from place to place. Within the Arctic ecozones, freshwater ecosystems are characterized by numerous lakes, many concentrated on the Canadian Shield, and an intricate network of surface drainage, culminating mostly in small rivers. Snow, ice, and permafrost determine storage and circulation of water (Woo 1993). The major form of water storage in the Arctic ecozones is snow, although glaciers also store water in the eastern Arctic.

Ice cover on lakes lasts longer than in adjacent ecozones, owing to reduced solar radiation and low air temperatures in winter. In general, spring comes late, releasing six to nine months of accumulated precipitation within several weeks and producing a high runoff. The largest annual flow from glacial drainage basins occurs later, during the short summer months (Woo 1993).

The brief summer season and harsh climate make the terrestrial Arctic one of the least biologically productive areas of the

Figure 9.1c
Labour force composition, 1991



Note: Using the 1970 Standard Industrial Classification, the four primary sectors have been grouped with their respective first-stage resource processing industries. For further details, see Endnotes

[a] "Other/Not defined" represents labour force categories that were less than 0.5% of the total labour force as well as responses for which the respondent did not specify the industrial category in which he/she or other household members were employed.

Source: Special tabulation prepared for the State of the Environment Directorate, Environment Canada, by Statistics Canada, based on the 1991 Census.

Figure 9.1d
Characteristics of the Arctic marine ecozones

Marine ecozone	August surface temperature (°C)	Presence of sea ice	Tidal range (m)
Arctic Basin	−1	All but the periphery is covered by 90+% multiyear ice	Almost nonexistent
Arctic Archipelago	0	Seasonal ice; open water 2–3 months in summer	Up to 8.0 in Wager Bay
Northwest Atlantic, northern part[a]	>0	Seasonal ice; occasional ice in waters off northern Labrador	Up to 14.5 in Ungava Bay

[a] Southern part of the Northwest Atlantic is discussed in Chapter 7

Source: Adapted from Department of Canadian Heritage (1995)

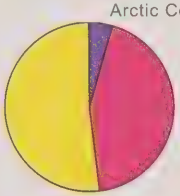
world on an annual basis, although occasional biological oases occur (Box 9.1). Arctic plants and animals have relatively slow reproductive and growth rates, slow sexual maturation, and long life spans. Ecosystems take a long time to recover from disturbance.

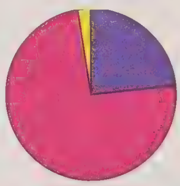
Despite permafrost that ranges from 100 to 1 000 m thick everywhere beneath the land surface, low-growing plants grow in the shallow (20–25 cm) active layer (the layer that thaws in the summer and can reach depths of 1.0 m; e.g., Chesterfield Inlet) wherever there is soil. In general, the diversity of native vascular plants decreases as one goes north: there are about 3 000 in temperate ecozones, about 600 in the Southern Arctic ecozone, and about 140 in the Northern Arctic ecozone. Mosses and lichens, on the other hand, increase in diversity: from 500 in temperate regions to up to 1 000 in the Arctic ecozones. In total, 40 vascular plant species are at risk in Canada's Arctic and Taiga ecozones (Conservation of Arctic Flora and Fauna 1994). According to the Conservation of Arctic Flora and Fauna International Working Group (1994), 1 400 plant species occur in the world's circumpolar region.

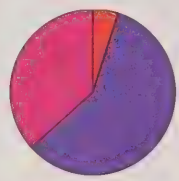
Only 30 of the world's 4 000 species of terrestrial mammals are found in the Arctic ecozones. Although the Canadian Arctic supports this country's only significant populations of certain large terrestrial mammals — for example, Muskox — the presence of only a few insect, spider, and mite species and the absence of reptiles and amphibians further illustrate the low species diversity in these ecozones.

Figure 9.1e

Land cover distribution







Note: For definitions of surface cover types, see legend to Figure 10.11 in Chapter 10.

Source: National Oceanic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR) imagery; Manitoba Remote Sensing Centre, Manitoba Department of Natural Resources.

Figure 9.1f

Air temperature, degree-days, and precipitation in selected centres

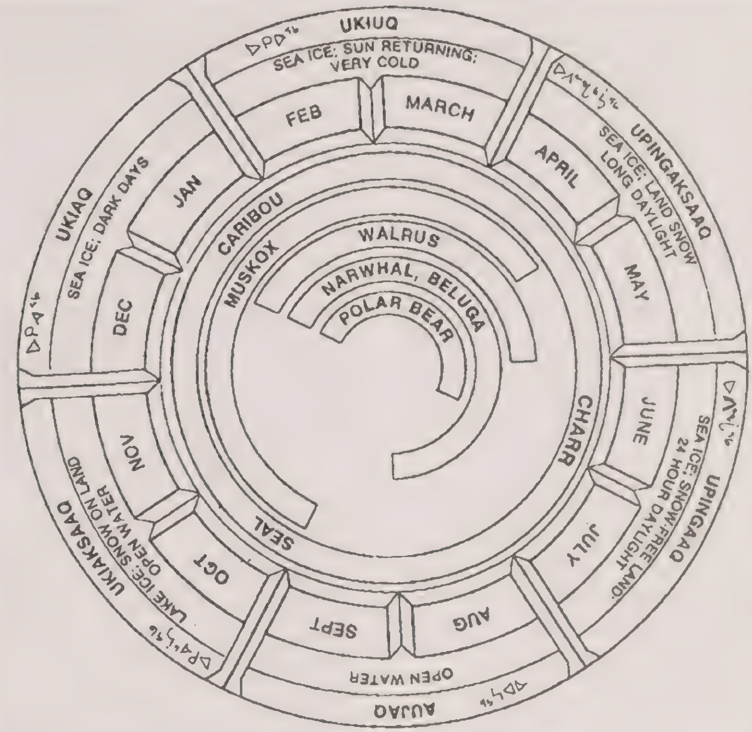
	Air temperature (°C)				Degree-days[a]		Precipitation			
Selected centres	Mean January maximum	Mean January minimum	Mean July maximum	Mean July minimum	Heating (<18°C)	Growing (>5°C)	Mean annual rainfall (mm)	Mean annual snowfall (cm)	Mean total precipitation (mm)	Days with measurable precipitation
Resolute, N.W.T.	–28.5	–35.8	6.8	1.3	12 630	29	50	97	140	98
Sachs Harbour, N.W.T.	–26.5	–33.5	9.6	2.8	11 592	122	50	84	127	83
Tuktoyaktuk, N.W.T.	–23.9	–31.2	15.4	6.4	10 414	410	75	67	142	69
Clyde River, N.W.T.	–23.0	–31.1	7.9	0.4	11 098	45	47	197	226	109
Kugluktuk, N.W.T.	–27.1	–34.4	14.4	6.0	10 743	337	103	114	215	N/A
Iqaluit, N.W.T.	–21.7	–30.0	11.6	3.7	10 050	177	193	257	424	152
Baker Lake, N.W.T.	–29.2	–36.2	16.1	6.0	11 011	389	144	130	262	110
Chesterfield Inlet, N.W.T.	–27.5	–34.8	13.2	4.6	10 815	269	138	129	269	N/A
Inukjuak, Quebec	–20.6	–28.3	13.1	5.1	9 063	333	251	175	418	151

Note: Data based on 1961–1990 climatic normals.
NA = not available.

[a] A unit of measurement of the deviation of the mean daily air temperature from a predetermined standard (at a particular location). For further details, see definition of degree-days in Glossary.

Source: Environment Canada (1994a).

Figure 9.2
Annual harvesting cycles



Source: Lancaster Sound Regional Land Use Planning Commission (1988).

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has judged 12 indigenous Arctic animal species, subspecies, and populations (terrestrial and marine) to be threatened or endangered (Table 9.1).

Arctic Cordillera

The Arctic Cordillera is the only mountainous Arctic ecozone and the only one with permanent ice caps and glaciers. Its mountains, comprising deeply dissected Precambrian crystalline rocks, rise as high as 2 500 m. The coast is dominated by high relief and long, narrow fjords (Ecological Stratification Working Group 1996).

Winters are long and extremely cold and summers are short and cool, although the growing season is enhanced by long periods of daylight. Only July and August have mean daily temperatures above 0°C. Located in the northern portion of the ecozone, Eureka, Canada's coldest weather station, has an average annual temperature of –19.7°C and a February mean monthly temperature of –38°C (Phillips 1990). Total mean annual precipitation averages 250 mm or less, although it is much higher in Labrador, largely as a result of frequent Atlantic coastal storms in the fall; yearly rain and snow totals are typically 800 mm on the highlands of Labrador facing Davis Strait (Phillips 1990).

The Arctic Cordillera has the lowest species diversity of the Arctic ecozones. Wildlife is largely absent over much of the landscape, although the flora and fauna in local areas, such as the few terrestrial oases, can be surprisingly rich (Box 9.1). Total vegetation cover rarely exceeds 25%, with nonvascular plants making up 95% of whatever cover does exist. Terrestrial birds and mammals are sparse. Although a few land-based bird species occupy the warmer coastal margins, the nearby marine ecosystems sustain a more varied biota. Seabirds nest in colonies on the coastal cliffs and forage for fish and invertebrates in the adjacent seas.

Northern Arctic

Summers are short and cold, with mean daily temperatures above 0°C only in July and August. Daily winter temperatures average less than –30°C in the coldest part, the northern islands. Snow cover usually lasts from September to June, but snow can fall during any month. Annual precipitation is less than 250 mm, except in southeast Baffin, where it can exceed 500 mm. The northern islands have the least precipitation (100 mm), and the area is often referred to as a polar desert. Unlike a true desert, moisture is plentiful — in lakes and rivers, in the wetlands and frozen soil, in the snow cover, in the permanent ice, and in the Arctic Ocean.

The terrain varies from rolling lowland plains in the west to higher plateaus and rocky hills in the east. The size of shrubs decreases from south to north, and very low and flattened plants are characteristic of northern locales. Generally, where there are plants, sites are 40–60% vegetated, predominantly by herbs and lichens not more than 10 cm high. North of 70° latitude, less than 3% of the land is covered with vegetated oases of sedge or grassland tundra; large areas either have 5–20% vascular plant cover or are devoid of plants (Bliss et al. 1973). The region provides calving and summer range for Barren-ground Caribou, year-round range for Peary Caribou, Muskox, Arctic Hares, and lemmings, and, during the short summer, important breeding habitat for migratory birds.

Southern Arctic

Lowland plains and rolling uplands, including significant areas of bog overlying permafrost, characterize the landscape of the Southern Arctic ecozone. Outcrops of rock

are commonly found on hillcrests (Ecological Stratification Working Group 1996). Summers are cool, moist, and about four months long, and winters are long and extremely cold. Total annual precipitation is usually less than 250 mm in the west and up to 500 mm in the eastern portion (Phillips 1990) (Fig. 9.1f).

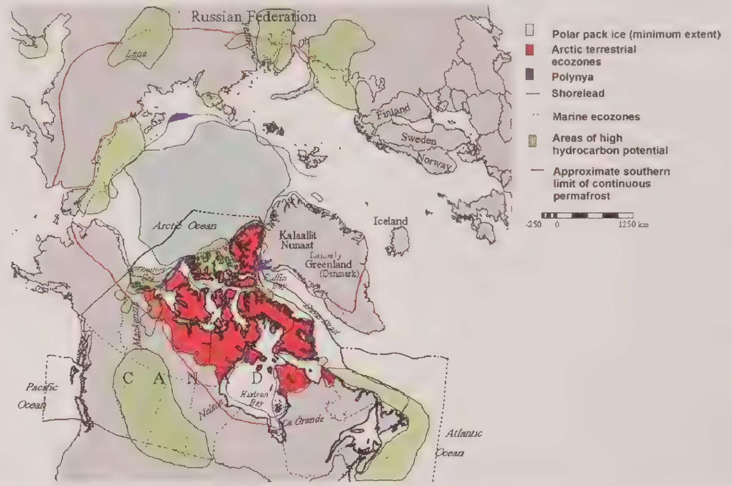
Of the three terrestrial Arctic ecozones, this one has the most extensive vegetative cover and highest species diversity. A nearly continuous cover of dwarf tundra vegetation, usually less than 30 cm tall, dominates the landscape, although major river valleys, such as those of the Coppermine and Thelon, can support small trees (Box 9.1). Shrubs of medium height, herbs, and lichens are characteristic. Wetlands are dominated by sedges and mosses.

Biophysical characteristics of marine ecozones

Canada's Arctic marine ecosystems extend from James Bay to the North Pole. In winter, the Arctic Ocean, with its immense fields of permanent ice and drifting ice floes, has a strong cooling effect on global weather, as it is mainly ice covered and acts essentially like a land mass. Even in summer, only about 10% of the Arctic Ocean is free of ice (Phillips 1990) (Fig. 9.1d). Like the Arctic Ocean, Hudson and James bays also act like a giant air conditioner, cooling coastal areas in summer.

Marine areas with relatively high diversity and abundance of wildlife, such as shoreleads (fractures in sea ice between pack ice and the shore) and polynyas (Fig. 9.3), are not widespread. The ones that have been identified are poorly understood. Many species have developed specific adaptations to survive in regions of recurring ice cover. The epontic community (living on the underside of the ice) is unique to these ecozones. When the ice is melting, the biota and nutrients on the under-ice surface fertilize the water, causing rapid growth of microscopic plants and crustaceans, which are eaten in turn by birds and marine mammals.

Figure 9.3
A circumpolar map of the Arctic showing areas of high hydrocarbon potential



Source: State of the Environment Directorate, Environment Canada.

Box 9.1
Marine and terrestrial oases in the Arctic

Marine oases

In the Arctic, humans have long tended to settle along the coasts near those ocean areas where the ice melted earliest in the spring; early hunting peoples were probably attracted to these biological oases by the local abundance of marine mammals. Among the first marine areas to open up in spring are shoreleads and polynyas. Areas of open water surrounded by ice, polynyas vary in size and shape (Fig. 9.3). They may be caused by an upwelling of warm water or by ocean currents, tidal fluctuations, or even wind, or by a combination of these elements (Stirling and Cleator 1981).

The recurrence and predictable location of shoreleads and polynyas, particularly those that remain open all winter, are of enormous biological importance. Generally, annual primary productivity in ice-covered waters is extremely low, and adjacent areas of open water are biological "oases" that provide birds and marine mammals with winter refuge and/or spring and fall feeding areas.

Large numbers of Walrus, Beluga, Narwhal, and Bearded Seals may overwinter in the North Water Polynya in northern Baffin Bay, and the Cape Bathurst Polynya, southwest of Banks Island, is a critical spring migratory waterfowl habitat. If severe winters prevent polynyas from opening, the results can be disastrous. In 1964, the Cape Bathurst Polynya failed to remain open, and approximately 100 000 waterfowl perished (Department of Canadian Heritage 1995).

Terrestrial oases

Usually poorly drained lowlands, biologically productive land areas include small areas on Herschel, Baffin, and Ellesmere islands that support extensive sedge meadows overlying shallow peaty soils. These oases are important to the survival of terrestrial Arctic flora and fauna (Nettleship and Smith 1975).

continued on next page

In the Arctic, there are more marine vertebrate species than terrestrial vertebrate species. Approximately 24 species of seabirds occur regularly in Arctic ecozones during summer. The Canadian Arctic supports this country's only significant populations of certain large marine mammals, such as Polar Bears, Walruses, Narwhals, and Bowhead Whales. Of the animals native to the Arctic marine ecozones, COSEWIC (1995) lists only whales as endangered (three species, five populations) and threatened (one species) (Table 9.1). However, COSEWIC can examine the status of only a limited range of species: species comprising more than half of the Arctic biomass, including the plants and animals of the ocean floor and many species of plankton and algae, are completely unknown.

Arctic Basin

There is essentially no shallow water in the Arctic Basin, and water depths are in excess of 2 000 m (Department of Canadian Heritage 1995). Sea ice up to 2 m thick covers 90–100% of its surface throughout the year (Fig. 9.1d). The waters have low biological productivity and diversity, because ice and snow cover block sunlight (Department of Canadian Heritage 1995). Open leads develop at all seasons. A few bird and marine mammal species visit the ice edges: fish and invertebrates are known to occur beneath the ice.

Box 9.1 (continued)
Marine and terrestrial oases in the Arctic

Arctic Cordillera ecozone

The high mountain ranges and icefields surrounding Lake Hazen on Ellesmere Island shield the region from cold winds in summer, and the climate there is exceptional, considering that it is at 81°N latitude. As a result, the flora (115 vascular plant species) and fauna (particularly insect species) are more diverse and abundant than at areas 8° (about 900 km as the crow flies) farther south. The land around Lake Hazen provides habitat for many Muskoxen and Arctic Wolves, and Arctic Charr in the lake are large and abundant.

Northern Arctic ecozone

Polar Bear Pass, on Bathurst Island, provides feeding sites for more than 50 species of birds, 26 of which nest there. Peary Caribou and Polar Bear travel across the lowland in regular seasonal movements. Muskoxen use the area year-round.

The marshy sedge tundra of the Great Plain of the Koukdjuak on Baffin Island is biologically rich and a critical nesting ground for geese. This oasis supports the largest goose colony in the world (one million geese) during the short summer. Approximately one-third of the Canadian breeding population of Lesser Snow Geese has been known to nest here, as has one-fifth of the Brant population that winters on the eastern seaboard of the United States. The Great Plain is crucial summer habitat to Barren-ground Caribou (Gillespie et al. 1991).

Southern Arctic ecozone

Herschel Island off Yukon's North Slope is exceptionally diverse and abundant in flora and fauna, including Arctic Fox and Polar Bears. The island is one of the few known nesting sites in the western Arctic for Black Guillemots, which are Arctic seabirds (Nettleship and Smith 1975).

A significant northward extension of the tree line occurs along the Thelon River valley. The Chippewyans refer to the valley as the place "where God began." It is one of the few places where the range of the Moose, a forest dweller, overlaps with that of the tundra-dwelling Muskox (Raffan 1993). In 1927, the Thelon Wildlife Sanctuary (56 000 km²) was set aside to protect the few remaining Muskox of the Thelon River valley. It lies two-thirds within Nunavut and one-third in Dene and Métis traditional territory. The Nunavut Land Claims Agreement requires that a management plan be set up to jointly conserve and manage the sanctuary. A parallel body, the Thelon Dezzeth Planning Committee, was formed to plan for the future of the western portion. A survey in January 1994 estimated the Muskox population at 1 100.

Arctic Archipelago

This marine region encompasses the seas around the Arctic islands, Hudson Bay, and James Bay. Most of this ecozone is largely ice free for two to three months in the summer and has landfast ice (sea ice growing close to shore) during winter; in the northwest, landfast ice persists all year (Fig. 9.1d) (Environment Canada 1994c). Hudson Bay is almost completely frozen from late December until late June (Phillips 1990).

The ecozone is "shelf-type," meaning that the water is shallow. Although biological productivity and diversity are generally low, concentrations of marine life occur, especially during the summer, near polynyas and shoreleads, where upwelling water mixes the layers above (Box 9.1). Mixing and increased productivity also occur where fresh water enters the Beaufort Sea from the Mackenzie River, and Hudson and James bays from numerous rivers. Migratory birds and marine mammals make intensive use of the ecozone during the ice-free period. The area provides localized major feeding habitat for several seabird species and major feeding and calving range for marine mammals.

Northwest Atlantic (northern portion)

The northern portion of the Northwest Atlantic ecozone maintains higher water temperatures than the other Arctic marine ecozones. It is a transition zone between polar waters and more southerly temperate waters under the influence of the Gulf Stream. The Gulf Stream may be more than 20°C warmer in water temperature (Environment Canada 1994c). Open water varies in location and extent. Ice begins to form off northern Labrador in November–December, and, by mid-July, the Labrador coast is ice free once again. In summer, icebergs are common, transported from more northerly regions.

Eastern Hudson Strait and Ungava Bay are among the most turbulent marine regions in the world. One of the world's highest tides occurs in southwestern Ungava Bay. The area is highly productive, particularly near the coasts of Kalaallit Nunaat (formerly Greenland) and Labrador (Department of Canadian Heritage 1995). The North Water, Canada's largest and best known polynya, is situated in northern Baffin Bay (Box 9.1).

Socioeconomic characteristics of Arctic ecozones

Population

With one of the lowest population densities in the world, the Arctic ecozones have a population of less than 28 000, scattered among 40 communities (Fig. 9.4; Table 9.2). Most of the population lives in coastal communities: only nine of these, all in the Northern Arctic ecozone, exceed 1 000 persons.

The Inuit — made up of regional groups that share a common heritage and one language with diverse dialects — form more than 80%, and their birthrate is almost double the Canadian average. The population grew by nearly 50% between 1981 and 1991 and is expected to double in the next 25 years. Compared with national averages, it is a markedly younger population, the workforce is noticeably less educated, and the per capita income is 60% lower.

Growth of towns is increasing demand for treatment of domestic sewage, solid waste disposal, and diesel fuel for generating electricity. Harvesting near communities puts pressure on local wildlife. With virtually no roads, most Arctic residents rely heavily on air and sea transportation. Thus, transportation is a major economic consideration within the Arctic ecozones (Box 9.2).

Economic activity

Residents of the Arctic ecozones are highly dependent on transfer payments from federal and territorial or provincial governments: for example, in 1988–1989, 86% of the budget of the Northwest Territories (which comprises the Taiga and Arctic ecozones) came from the federal government (GNWT 1989). Residents derive wages and cash from employment in various sectors (e.g., government, tourism, and resource development) and from commodity production (e.g., furs) (Fig. 9.1c). However, local economies are heavily based on "subsistence" hunting, trapping, and fishing (GNWT 1990; Environment Canada 1994b), for, despite living in settlements for several decades, Inuit retain strong ties to the land and sea. In the

Table 9.1

Endangered and threatened indigenous species, subspecies, and populations of wild fauna in the Canadian Arctic, according to the Committee on the Status of Endangered Wildlife in Canada, April 1995

Terrestrial			Marine		
Arctic Cordillera	Northern Arctic	Southern Arctic	Arctic Basin	Arctic Archipelago	Northern part of Northwest Atlantic
Endangered					
Mammals					
Wolverine eastern population	Peary Caribou Banks Island and high Arctic populations Wolverine eastern population	Wolverine eastern population		Bowhead Whale eastern and western Arctic populations White Whale (Beluga) SE Baffin Island–Cumberland Sound population	Right Whale Atlantic population White Whale (Beluga) Ungava Bay population
Birds					
Harlequin Duck eastern population	Harlequin Duck eastern population	Harlequin Duck eastern population Eskimo Curlew			
Threatened					
Mammals					
	Peary Caribou low Arctic population			White Whale (Beluga) eastern Hudson Bay population	

Source: COSEWIC (1995). Ecozone information compiled by J. Reid based upon the COSEWIC information in combination with range/distribution maps from COSEWIC status reports and various published wildlife authorities.

mixed subsistence/cash economy that has emerged, cash from employment is often used to buy the tools needed for subsistence hunting and fishing.

The Arctic ecozones are rich in mineral and hydrocarbon resources (Fig. 9.5). In 1990, nearly 40% of the gross domestic product (GDP) for the Northwest Territories was attributed to the resource sector, compared with the Canadian average of about 17%. But Arctic resources are hard to get at and expensive to develop, and, like natural resources everywhere, they are strongly influenced by international market conditions.

Minerals and mining

The economic importance of mining to the economy of the Arctic is significant, despite the fact that the majority of the benefits go to the people of southern Canada, rather than to the people of the Arctic ecozones (GNWT 1989). Mining is the largest economic sector in the Northwest Territories portion of the Arctic ecozones, accounting for 75% of the value of goods and services produced, over 25% of the GDP, and 10% of all salaries and wages (T. Hoefer, Northwest Territories Chamber of Mines, personal communication). Mining has been and continues to be a major influence on the development of transportation, construction, and service industries.

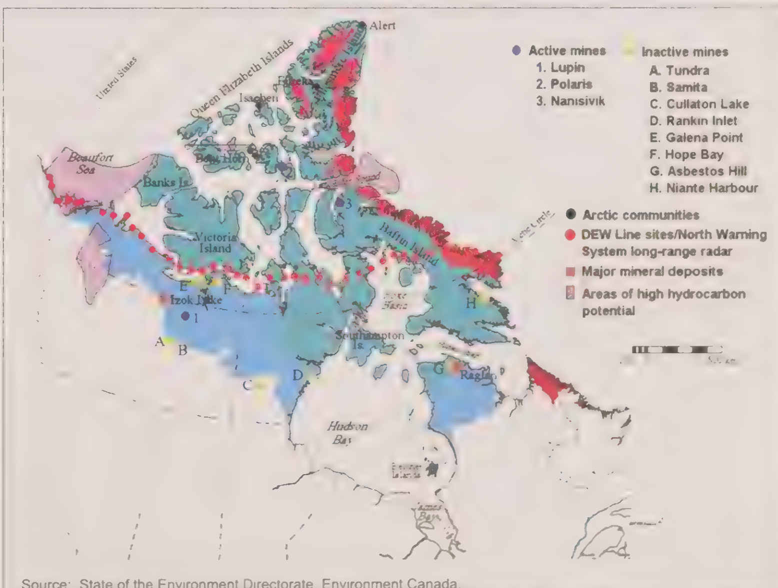
There are three operating underground mines in the Arctic ecozones: the base metal mines at Polaris and Nanisivik and the Lupin gold mine (Fig. 9.5). All three mines provide employment opportunities for Arctic communities. The projected life spans of these mines depend on several factors, including size of deposit, costs of operation, and value of the product on the international market. The value of total metallic mineral production in the Northwest Territories has fallen drastically over the last few years — from $935 million in 1989 to $392 million in 1993 — owing to global recession and the closure of the large Pine Point base metal mine (Hoefer 1994).

In contrast, exploration expenditures in the Northwest Territories rose from a low

Figure 9.4
Terrestrial ecozones, communities, and land claim areas in the Canadian Arctic

Source: State of the Environment Directorate, Environment Canada.

Figure 9.5
Areas of high hydrocarbon potential, active and inactive mines, and former DEW Line sites (some replaced by the North Warning System)



Source: State of the Environment Directorate, Environment Canada.

of $29 million in 1991 to $158 million in 1994. This dramatic jump, the highest ever in Canada, was largely due to the discovery of diamonds in the Slave Geological Province north of Yellowknife, which touched off the largest mineral rush in Canadian history. Since then, the likelihood of the establishment of Canada's first diamond mine continues to increase. In Arctic Quebec, the Raglan property, one of the world's largest known nickel–copper deposits, has been approved for opening in 1998; this opening could create 400 jobs, with 20% going to Inuit. Record staking and record expenditures occurred in 1994 for base metals and gold (Natural Resources Canada 1995). On the other hand, a major zinc–copper prospect at Izok Lake, N.W.T., may not come into operation, given the low market price and lack of transportation. All this exploration could dramatically change the economic situation in the Arctic ecozones.

Hydrocarbon development

Oil remains the world's major source of energy, accounting for almost 40% of primary energy demand; natural gas accounts for 21%. The circumpolar Arctic has some of the largest hydrocarbon reserves in the world (Fig. 9.3). Estimates suggest that reserves between 100 and 200 billion barrels of crude oil and between 57 and 85 trillion cubic metres of natural gas are located in the circumpolar region.

Three decades of exploration in the Canadian Arctic resulted in 53 oil and gas discoveries in the Mackenzie Delta and the Beaufort Sea, 19 in the Arctic islands, and one offshore in the eastern Arctic. Bent Horn on Cameron Island in the Arctic Archipelago is the only producing field. The Mackenzie/Beaufort field has proven to be one of the richest in the world. With Native land claims largely resolved in the Arctic ecozones, companies have shown renewed interest, and a revival of activity is likely over the next few years.

Tourism

The natural environment of the circumpolar regions attracts thousands of tourists, and tourism in the Arctic ecozones has grown substantially in recent years. In 1994, an estimated 64 000 tourists visited the Northwest Territories, with about 40% touring the Arctic ecozones (V. Johnson, Environment Canada, personal communication). Tourism is the third leading industry of the Northwest Territories (Hinch 1995; Lundgren 1995): in 1989, it contributed $54 million to the Northwest Territories economy, accounting for 2.7% of the gross territorial product (Hinch 1995). However, the amount generated in the

Table 9.2
Populations of the Arctic ecozones, 1981–1991

Ecozone	Official name	Local name	Population 1981	Population 1991	% change, 1981–1991
Arctic Cordillera	Broughton Island	Qikiqtarjuaq	378	461	18.0
	Clyde River	Kangirtugapik	443	565	21.6
Total			821	1 026	20.0
Northern Arctic	Akulivik	Akulivik	256	375	31.7
	Arctic Bay	Tununirusiq	375	543	30.9
	Baker Lake	Qamani'tuaq	815	1 186	31.3
	Cambridge Bay	Iqaluktuuttiaq	815	1 116	27.0
	Cape Dorset	Kinngait	784	961	18.4
	Gjoa Haven	Ursuqtuuq	523	783	33.2
	Grise Fiord	Ausuittuq	106	130	18.5
	Holman	Uluqsaqtuuq	300	361	16.9
	Igloolik	Iglulik	746	936	20.3
	Iqaluit	Iqaluit	2 333	3 552	34.3
	Ivujivik	Ivujivik	na	263	–
	Kimmiruta	(Lake Harbour)	252	365	31.0
	Pangnirtung	Pannirtuuq	839	1 135	26.1
	Pelly Bay	Arviligjuaq	257	409	37.2
	Pond Inlet	Mittimatalik	705	974	27.6
	Repulse Bay	Naujaat	352	488	27.9
	Resolute	Qausuittuq	168	171	1.8
	Sachs Harbour	Ikaahuk	161	125	–28.8
	Sugluk	Salluit	480	823	41.7
	Taloyoak	Talurjuaq	431	580	25.7
Total			10 698	15 276	30.0
Southern Arctic	Arviat	Arviat	1 022	1 323	22.8
	Aupaluk	Aupaluk	102	131	22.1
	Bathurst Inlet	Qinngaut	20	18	–11.1
	Bay Chimo	Umikmaktuuk	60	53	–13.2
	Chesterfield Inlet	Igluligaarjuk	249	316	21.2
	Kugluktuka	(Coppermine)	809	1 059	23.6
	Coral Harbour	Sallit	429	578	25.8
	Inukjuak	Inujjuaq	661	1 044	36.7
	Kangiqsujuaq	Kangirsujuaq	229	404	43.3
	Kangirsuk	Majuriajuaqiut Akillingit	na	351	–
	Paulatuk	Paulatuuq	174	255	31.8
	Povungnituk	Purvirnituq	na	1 091	–
	Quaqtaq	Quartaq	145	236	38.6
	Rankin Inlet	Kangiqliniq	1 109	1 706	35.0
	Sanikiluaq	Sanikiluaq	383	526	27.2
	Tuktoyaktuk	Tuktuujaartuq	772	918	15.9
	Whale Cove	Tikiraqjuaq	188	235	20.0
Total			6 352	10 244	38.0

na = not applicable

[a] Changed since the previous edition of *The state of Canada's environment* (Government of Canada 1991).

Source: Bureau of Statistics, Government of the Northwest Territories, Yellowknife.

Northwest Territories portion of the Arctic ecozones is substantially smaller: in 1993, tourism generated $11.8 million for Arctic businesses.

Northwest Territories tourism revenue is expected to increase by approximately 35% by 1999. The greatest increase is predicted for recreational hunting, which is expected to rise approximately 60% during the same period. Parks and historic sites are major attractions and play a small but significant part in local economies. In the last 10 years, Arctic cruises have expanded in terms of the number of companies, number of cruises offered, passenger capacity, and range of destinations. Ecotourism is increasingly popular, and dog team expeditions, naturalist lodges, and naturalist tours to the edge of ice floes attract visitors from around the world. In 1994, there were over 130 naturalist/hunting/fishing tour operators in the Arctic ecozones (GNWT 1995a).

Some traditional Inuit activities are integrated into the tourism industry in the form of big game hunting for Polar Bear, Muskox, and Barren-ground Caribou. Recreational hunting for Polar Bear, with some 60 hunts a year, is the backbone of this industry for several Northwest Territories communities. A Polar Bear hunt of five to six days costs an average $15 000, of which more than half remains in the community.

Commercial harvesting

The animal rights campaigns in the 1980s caused a dramatic decline in the markets for sealskin and fur, and this had a substantial impact on cash incomes (see section entitled "International barriers to sustainable use of biological resources"). The eastern Arctic still has not recovered from the collapse of the European sealskin market (K. Emmett, Government of the Northwest Territories, personal communication). In an effort to revitalize the Canadian sealskin market in the late 1980s, the North-based Nunasi Corporation started a leather business that is devoted to the marketing of fine sealskin products. A small-scale sealskin tannery was recently opened in Broughton Island. Three species of seal are taken. Commercial trappers still take several species of furbearers. Fur production remains an important part of the Inuit economy, particularly in the western portion of the ecozones (GNWT 1990).

In addition to fur and sealskin, wild meat, fish, handicrafts, and art are sold. Recently, Muskox and Caribou meat have been exported from the Arctic. In the Northwest Territories, 80–100 commercial hunters take $1.5 million worth of Caribou and Muskox for food. There is a limited trade in Muskox meat to southern Canada. Although sales of Caribou meat from the Beverly and Qamanirjuaq herds are restricted to the Northwest Territories, large quantities of Caribou meat from Southampton Island were sold in the South in 1995. Workers in Cambridge Bay process and package Caribou and Muskox meat and distribute it to consumers across the Northwest Territories, thus making these meats widely available and supplying income to harvesters. A butchery in Rankin Inlet also distributes traditional meat within the Northwest Territories. Since 1994, four northern Quebec communities have been engaged in commercial hunting and processing of Caribou on a quota of 1 800 animals per community. A private company has obtained a quota of 3 000 Caribou annually (T. Beaudet, Ministère de l'Environnement et de la Faune, Gouvernement du Québec, personal communication). Since 1986, Inuit in northern Labrador have been developing a modest annual harvest of George River Caribou for export to domestic and international markets through the Labrador Inuit Development Corporation (J. Rowell, Labrador Inuit Association, personal communication).

Inuit in Labrador have over 200 years of commercial fishing experience, with Atlantic Cod, Atlantic Salmon, and Arctic Charr being the traditional species. Labrador Inuit are also exploring opportunities for expanding into trade in nontraditional species, such as scallops, shrimp, and Greenland Turbot. The Inuit of Baffin Island and northern Quebec, sole owners of Unaaq Incorporated (W. Slipchenko, environmental consultant, personal com-

Box 9.2
Transportation infrastructure

Virtually all 40 Arctic communities depend on air transport for year-round access and on marine transport for resupply. Although dry cargo tonnages have remained stable in recent years, demand for bulk fuel has increased at about 3% per year.

Roads

Except for a 40-km stretch between Nanisivik and Arctic Bay, all-weather roads in the Arctic ecozones are for local community access only. When water transport is no longer possible, land vehicles travel over the frozen surface. Winter roads and snowmobile trails link communities. A winter road from Yellowknife is used to supply the Lupin mine, 400 km northeast of Yellowknife.

Water transport

Water transport is fundamental to the annual resupply of fuel and most dry cargo to the mines at Nanisivik (northern Baffin Island) and Polaris (Little Cornwallis Island), the oilfield at Bent Horn (Cameron Island), and all communities and North Warning System (NWS) sites across the Arctic ecozones (Fig. 9.5). From Polaris and Nanisivik, ore is shipped to Europe, and the Bent Horn oilfield ships out two tanker loads of crude oil each year. Virtually every community in the Arctic depends on boats for summer travel.

Air transport

All communities except Bathurst Inlet and Bay Chimo have airports. There are scheduled flights for passengers and freight at least weekly to every community. Gold bars are flown south from the Lupin mine. Chartered aircraft support such activities as exploration, hunting, tourism, and scientific research.

munication), are expanding their horizons outside Canada. They have been active since 1987 in international exporting of northern products into Asia and Europe, and the company proposes establishing a northern prawn fishery in the far eastern Russian Federation. In 1994, a division of Unaaq, employing about 100 Inuit, generated over $600 000 in the shrimp and turbot fishery. In the western Northwest Territories, there is a well-established anadromous charr fishery at Cambridge Bay and small-scale seasonal fisheries in most communities (GNWT 1994b). In the eastern Northwest Territories, although commercial fishing is a new industry, the Pangnirtung fishery on Baffin Island generated $1.5 million in sales in 1993. The fishery purchased fish from 98 fishermen, employed 33 workers, and processed 374 t of turbot and 43 t of charr.

Since the 1950s, an important source of income for harvesters has been the production of arts and crafts from bone, ivory, soapstone, and hides. According to the 1989 Northwest Territories Labour Force Survey, the level of involvement in traditional crafts, such as needlework, printmaking, and carving, was 30% for Inuit, the majority on a part-time basis (GNWT 1990). In a few Northwest Territories communities in the eastern Arctic, income from carving surpassed that from fur sales. Like fur trapping, carving is a flexible occupation that could be adapted to a hunter's schedule. In 1980–1981, total income for carvers was about $3.6 million in the Northwest Territories. By 1982–1983, this had declined by 62%, exhibiting the same instability as trapping income. The Northwest Territories carving industry has been recovering since 1983.

Subsistence economy

The subsistence economy has sustained the Inuit for generations and shows no signs of dying away (GNWT 1989). Many Inuit, perhaps most, consider themselves to be either full-time hunters or trappers or part-timers who supplement their wild harvest with wages. Even for those Inuit employed full-time as wage earners, weekend and part-time hunting and fishing remain important means of augmenting their household food supply with local fish and game. Hunting is valued for its contribution to independence, self-esteem, respect from others, traditions, family relationships, and a healthy lifestyle. However, annual capital and operating costs for harvesting activities may run to more than $10 000 per harvester. Hunters and trappers have turned to the welfare system to obtain cash to sustain their traditional way of life. Because of the stigma attached to welfare, it tends to cast the role of the hunter and trapper in a negative light (GNWT 1989).

The economic value of this subsistence economy is a very important component of many communities and is often unrecognized in conventional economic accounting. Country food (Box 9.3) is an important part of Inuit diet and significantly augments household income, as it provides Inuit with traditional clothing and a healthy diet at much less cost than imported food and clothing. This is an important consideration, as the cost of living, particularly the cost of store-bought food and housing, is elevated in the Arctic; it is 50% higher in Sanikiluaq than in Montreal (1992) and 110% higher in Sachs Harbour than in Edmonton (1994), the closest major centre.

Although the Inuit make use of a variety of plants for food and medicinal purposes, fish and game, particularly marine mammals, are their main sources of food. In 1991, the percentage of Inuit reporting all or most of their meat, fish, and fowl obtained from hunting and fishing was 63% in the Northwest Territories (Lawn and Langner 1994a), 56% in Quebec, and 27% in Labrador (Lawn and Langner 1994b). The replacement value of country food in Nunavut has been estimated at a minimum of $37 million annually (GNWT 1994b). In Clyde River, Baffin Island, the 450 residents consume about 100 t of seal meat each year; to replace this with imported food would cost $1 million (Bone 1992).

Human Activity and the Arctic Environment

Global issues

The Arctic is often perceived as pristine, far removed from the polluting effects of human activities. In recent decades, however, evidence has been growing that the Arctic, with few contaminant sources of its own, is receiving significant amounts of contaminants from other parts of the globe (Box 9.4). In addition, Arctic ecosystems are affected by climate change and, indirectly, global trade barriers.

Pollutants from distant sources

Most precipitation falls as snow, bearing with it contaminants from the atmosphere. Snow sampled from land, sea ice, and lake surfaces shows traces of organochlorines, heavy metals, and radionuclides. As snow melts, it releases these contaminants into its surroundings, where they can be taken up by aquatic microorganisms, fish, mammals, and birds or transported by ocean and river currents.

This long-range transport of contaminants from industrialized and agricultural regions is increasingly viewed as one of the most significant threats to the Arctic environment (DIAND 1996a) (see Chapter 1, Fig. 1.3). Drill core samples from the Ellesmere ice cap indicate a century-long record of industrial pollution in the Canadian Arctic. Soot, acid-forming substances, polychlorinated biphenyls (PCBs), pesticides, and other contaminants from distant sources in industrialized and developing countries are found in measurable quantities in Arctic waters, sediments, snow, air, and biota. A 75% increase in worldwide pollution has occurred since 1956 (Phillips 1995), despite international pollution controls that have decreased the levels of many pollutants; for example, at Alert on Ellesmere Island, levels of the insecticide lindane (i.e., hexachlorocyclohexane, or HCH) have dropped 90% since 1979, and lead concentrations have decreased by 55% since 1980 (Phillips 1995). Nonetheless, new pollutants have boosted worldwide pollution levels.

Box 9.3
Country food — benefits of a traditional diet

Wild, or "country," food provides the Inuit with a healthy diet from local sources at much less cost than food imported from the South, thus making a significant addition to household income. Its gathering and distribution are the basis of social activity and maintain social bonds (Wheatley 1994, 1995). The country foods consumed in largest quantity in the Northwest Territories are Caribou, seal, and Arctic Charr, with lesser amounts of muktuk (whale skin used for food), ptarmigan, Walrus, and Polar Bear.

The Europeans who first established contact with Native people remarked on their excellent health and ability to recover from wounds. Nutritional problems resulted from shortages in the food supply owing to natural forces rather than nutritional deficiencies inherent in a poor diet. Today, research indicates that the benefits of country food and a traditional lifestyle outweigh the risk of contaminant intakes that may be associated with a traditional diet.

Alternatives to traditional foods that have similar nutritional value are not readily available to northerners, are more expensive, and are considered less palatable. Unlike traditional food, store-bought food does not contribute to social well-being and community cohesiveness. The types of store-bought foods sold in Arctic communities tend to be high in carbohydrates, fats, and sodium and low in protein, vitamins, and other essential nutrients. Country food, on the other hand, is a much richer source of a number of elements, such as iron, magnesium, and calcium, than imported foods. For example, seal meat has 6–10 times the iron content of beef, and seaweed, wild greens, and berries can provide supplementary vitamins and minerals.

A diet of local meat and fish can provide all the energy requirements and nutrients that the Inuit require. The traditional Native diet is high in protein, is low in carbohydrates, and has a fat content similar to that of a "southern" diet. The consumption of all of the edible parts of a Caribou or seal provides the majority of nutrients that would have to be obtained from a variety of food groups in a typical "southern Canadian" diet. As well, marine mammals and fish provide Inuit with the majority of omega-3 fatty acids in their diet. A diet rich in fish and marine mammals has been linked to a lower incidence of thrombotic disease (e.g., angina, heart attack) in Kalaallit Nunaat and Japan (Dyerberg et al. 1975; Yamori et al. 1985). Indeed, for Inuit living along the shores of Hudson Bay, death owing to ischemic illnesses (circulatory problems) is highly rare, if not nonexistent (A. Corriveau, Mackenzie Regional Health Board, Government of the Northwest Territories, personal communication). Moreover, polyunsaturated fatty acids are increasingly recognized as having a beneficial effect upon visual acuity. Recent studies would also tend to indicate that omega-3 fatty acids influence high birth weight and prolong the gestation period (Olsen et al. 1992), an essential factor in child development (Nettleton 1993).

Country food risk

The first suggestions that contaminants were present in country foods in Canada came in the early 1970s in Ontario and Quebec, when methylmercury from local industrial sources was found to have polluted nearby ecosystems, on which Aboriginal people depended for food. Since then, other heavy metals, organochlorines, and other toxic substances, often from distant sources, have been identified in Arctic food chains. Aboriginal people who harvest and consume country food containing pollutants face a potential threat to their physical, mental, and cultural well-being (Usher et al. 1995).

Knowledge about the impact of contaminants on human health is limited. Inuit depend on the health and stability of Arctic ecosystems, as they derive most of their nutrition from country foods. Hence, Inuit are more likely than southerners to accumulate contaminants from their diet. Isolating adverse human health impacts as a result of contaminants in food is extremely difficult. Health depends on many factors: for example, cigarette smoking places residents at much greater risk of cadmium exposure than traditional diet.

Although there are higher than normal levels of contaminants in country foods, levels high enough to pose health risks are not widespread, although further studies are needed to monitor the long-term risks associated with the exposure of fetuses and breast-fed newborns to food chain contamination (DIAND 1996a). High levels generally occur in particular species, more often in an internal organ than in the whole animal. The Centre for Indigenous Nutrition and Environment, the Quebec government, and Health Canada advise on safe quantities and types of food. For example, traditionally hunted birds, such as geese, grouse, and ptarmigan, and their eggs are safe to eat, as they do not accumulate high levels of contamination. Levels of cadmium (a heavy metal) and cesium (a radionuclide) in Caribou meat are low, and there is no current human health risk. Health advisories have been issued to limit consumption of the kidney and liver of Caribou from the George River herd in Labrador owing to elevated cadmium levels (Usher et al. 1995; J. Rowell, Labrador Inuit Association, personal communication). As well, Lake Trout in many Northwest Territories and northern Quebec locations frequently exceed Health Canada's mercury limit guidelines of 0.2 mg/kg for subsistence and 0.5 mg/kg for commercial fish consumption. Preliminary results determined that water, sediment, and fish in rivers are less contaminated in the Arctic than in the South.

Arctic ecosystems are particularly vulnerable to contaminants. Compounds that have been transported over long distances in a gaseous or vapour form tend to condense in these colder temperatures. The degradation process that breaks contaminants down into harmless substances is inhibited by cold temperatures and reduced solar ultraviolet radiation. In addition, PCBs and certain pesticides are very persistent and highly "lipophilic," which means that they tend to concentrate in fatty tissue. These compounds bioaccumulate readily in fatty tissues of long-lived animals at the tops of food chains, such as marine mammals (e.g., Polar Bears, seals, whales), terrestrial animals (e.g., Caribou), seabirds (e.g., Glaucous Gull), fish (e.g., Arctic Charr), and hunters and their families. The long marine food chains allow persistent contaminants to become highly concentrated in top predators, such as Polar Bears and humans.

The contaminants of greatest concern in the Arctic fall into three groups — persistent organic pollutants (POPs), heavy metals, and radionuclides (Table 9.3). Scientists are studying and monitoring Arctic ecosystems to try to determine levels at which harmful effects appear. To date, no recorded changes in the physiology, behaviour, or community structure of Arctic fish or wildlife have been associated with current contaminant levels. Within the Arctic ecozones, no significant clinical effects have been found in humans, although preliminary results suggest that exposure to POPs may be associated with reductions in male birth size and reduced infant immunity (DIAND 1996a).

Current knowledge of the sources of these substances and their fates in the Arctic environment is quite variable, depending on the substance. Although levels in food chains of two heavy metals, mercury and lead, have been relatively well documented, debate continues over what proportion of each type of contaminant is anthropogenic (human-induced) versus natural (i.e., in natural geology). Studies on the occurrence of radionuclides in the Arctic date back to the early 1960s. Organic contaminants have been detected since the early 1970s, but only in the last few years have efforts intensified to inventory global production and trace their national and global pathways. One such effort is the international Arctic Monitoring and Assessment Programme of the Arctic Environmental Protection Strategy (AEPS).

Box 9.4
Arctic haze

Sparsely settled and far from the cities of the south, the Arctic could be expected to have some of the cleanest air in the world. Yet, ever since the 1950s, pilots and other observers have reported extensive layers of reddish-brown haze in the Arctic atmosphere during winter. Covering a region the size of Africa, the haze is made up of very small solid or liquid particles containing a wide variety of contaminants and natural compounds, including sulphate compounds. It is confined to the lowermost 1–2 km of the atmosphere. Over time, these transform into microscopic acid-forming particles, similar to the particles that cause acid deposition at lower latitudes. This makes the Arctic's winter air some 10–20 times more polluted than Antarctica's and some 10 times more polluted than that over the least polluted regions of North America (Phillips 1995).

In winter, prevailing winds transport contaminants from industrialized parts of the world into the Arctic (see Chapter 1, Fig. 1.3). Ocean currents and sea ice may also transport pollutants (Feshbach and Friendly 1992). Up to two-thirds of Arctic haze originates in the heavily industrialized nations of eastern Europe and the Russian Federation, which lie under major global air pathways. North America contributes less than 4%, because wind carries pollution eastwards over the Atlantic Ocean, where storms rinse the pollution out of the air and into the ocean (Phillips 1995).

Arctic air becomes 20–30 times more polluted in winter than in summer (Phillips 1995). Arctic haze reduces visibility in winter. It also increases the amount of solar radiation trapped in the troposphere. This, together with the increased blackness of the top layers of snow covering the ground, which absorbs solar radiation, can change incoming and outgoing radiation and has the potential to modify global climate. Relatively little is known about the effects of haze on ecosystems. Because Arctic ecosystems are uniquely vulnerable, it is possible that although pollution levels even in winter are lower than those in southern urban areas, the consequences may be greater.

Sources and transport

The primary transport mechanism for contaminants appears to be atmospheric currents, followed by north-flowing rivers and ocean currents, as well as migrating birds, fish, and marine mammals. The debate over the sources of the heavy metals that now contaminate food chains will remain unresolved until more accurate and complete information about emissions becomes available. Estimates on pesticide use now available from North America and Europe are better than those from the Russian Federation (DIAND 1996a).

- *Atmospheric transport*: Stronger air flows to the Canadian Arctic occur in winter and are predominantly from Eurasia; some air currents flow from southern Canada and the United States in summer (see Chapter 1, Fig. 1.3). The Arctic acts as a "heat sink," absorbing heat transported from southern latitudes via global air circulation. Air currents carry organochlorines, heavy metals, smoke, dust, acid-forming substances, and radioactive fallout. Snow and rain are major mechanisms for transferring organochlorines from the air to water and land. This helps to explain why Arctic rivers draining relatively undeveloped terrain have been found to have higher contaminant loads than the Mackenzie River, which drains populated areas (Jeffries and Carey 1993). In addition, measurements in annual snowpack layers show that snow and ice can play a significant role in storing and reemitting more volatile contaminants, such as chlorinat-

ed pesticides (Gregor 1991, 1993). Mercury and semivolatile organics can volatilize from snow, plant, and soil surfaces; this results in an ongoing sequential migration of long-lived, semivolatile compounds to colder climates (Wania and Mackay 1993), owing to repeated volatilization from the land or water surface to the atmosphere, followed by scavenging from the atmosphere. Snow is even more effective than rain at removing these contaminants from the atmosphere. Low temperatures encourage condensation, meaning that these contaminants tend to accumulate in the Arctic ecozones.

- *Freshwater transport*: Rivers in northern Asia, Europe, and North America are conduits of contaminants to the Arctic Ocean from point sources and surface runoff. Three major rivers in the Russian Federation and the Mackenzie River in Canada contribute most freshwater inputs into the Arctic Ocean (Fig. 9.3). The Nelson River in Manitoba and the La Grande River in Quebec are important sources of fresh water to Hudson and James bays. The total riverine input leading to the Arctic Ocean is still thought to be considerably less than that from the atmosphere.
- *Ocean transport*: Because oceanic circulation is much slower than atmospheric (years vs. days), ocean currents bring in smaller amounts of contaminants than the atmosphere. Water transported to the Arctic Ocean originates from the deep layers of the North Atlantic Ocean. However, levels of some organochlorines decrease with depth in the Arctic Ocean. This suggests that these contaminants are mostly deposited from the atmosphere directly and in runoff and melting snow and ice (Hargrave et al. 1992). Recent evidence suggests that the Arctic Ocean is also becoming a source of some POPs.

Uptake by marine ecosystems

In a food-limited environment such as the Arctic Ocean, organisms rapidly use concentrated organic material (Muir et al. 1992). Contaminants that are adsorbed or attached to particulate matter in the water column are readily taken up by plankton and other filter feeders. They are then accumulated in fatty tissues, in the case of organochlorines, or in protein-rich tissues, in the case of metals. Prominent contaminants in marine biota are toxaphene (a common name for the group of compounds known as the polychlorinated bornanes), PCBs, dichlorodiphenyltrichloroethane (DDT), and dichlorodiphenyldichloroethylene (DDE) (Muir et al. 1992). Many of these contaminants tend to persist in these tissues, and the predator at each higher level of the food chain accumulates the total contaminant burden of all its prey. Marine mammals are top predators in the Arctic marine food web. That Polar Bears, whales, and seals generally contain higher levels of organochlorine contaminant levels than other northern animals (DIAND 1996a) is a result of their position at the top of long food chains, high fat content of their bodies, and the length of time that they live and accumulate contaminants.

PCBs and DDT are the most prominent contaminants in seal and Polar Bear blubber, and toxaphene is the most prominent in Narwhal and Beluga blubber. Although PCB levels in Arctic Beluga are about 10–20 times lower than those found in St. Lawrence River Belugas, they are still high enough to be of concern. Narwhal and Beluga tissues (kidney, liver) also have elevated concentrations of heavy metals (DIAND 1996a). Generally, in Ringed Seal, mercury levels have been increasing in recent years, whereas cadmium levels have not changed in 10 years (Wagemann et al. 1996).

Uptake by freshwater ecosystems

A wide range of concentrations of PCBs and other organochlorines, as well as mercury, is seen in freshwater fish, such as Lake Trout and Lake Whitefish, although generally at much lower levels than in marine mammals. The most prominent contaminants in Arctic Charr are toxaphene from atmospheric sources and methylmercury from natural sources (Muir et al. 1992). As in marine ecosystems, transfer of contaminants up freshwater food chains may explain the differences in contaminant levels in predatory freshwater fish. Commercial northern fish species are closely monitored, and fish may not be sold in Canada if mercury levels exceed 0.5 mg/kg. Generally, in the last

Table 9.3
Major toxic contaminants and their anthropogenic sources or uses

Contaminants of concern	Anthropogenic sources or uses
Persistent organic pollutants	
PCBs	Electric transformers
DDT and DDE	Agricultural and disease-controlling pesticides
Toxaphene	
Chlordane	
Hexachlorocyclohexane	
Hexachlorobenzene	
Aldrin, dieldrin, endrin	
Polycyclic aromatic hydrocarbons	Incomplete combustion of organic material (such as fossil fuels)
Heavy metals	
Cadmium Mercury Lead	Industrial activities (such as coal burning, ore smelting), automobile exhaust, impoundment related to hydroelectric dams
Radionuclides	
Cesium Strontium Plutonium	Atmospheric weapons testing, accidental discharges, ocean dumping

Source: Barrie et al. (1992).

20 years, mercury levels have been constant in freshwater and anadromous fish (Lockhart 1995).

Uptake by terrestrial ecosystems

The air/plant/animal pathway is the major route followed by many contaminants. Airborne contaminants, particularly organochlorines, are deposited on vegetation, eaten by and concentrated in herbivores (Caribou, Muskoxen), and further bioaccumulated by carnivores (Polar Bears, Wolves) and eventually humans. The most prominent contaminants in terrestrial biota are lindane and hexachlorobenzene (HCB). Southern Baffin Island Caribou herds have the highest PCB levels (Elkin and Bethke 1995), although levels are much lower than in southern domestic animals (Ryan and Norstrom 1991). In general, organochlorine levels are lower in terrestrial mammals than in marine mammals owing to shorter land food chains. Spatial trends show an increase in PCBs, chlordane (an insecticide), and DDT from west to east in Caribou (Elkin and Bethke 1995). Caribou, however, are long-lived herbivores and can bioaccumulate significant levels of heavy metals, such as cadmium. Elevated cadmium levels in Caribou kidneys are due to natural sources and accumulated airborne contaminants in lichen, their dietary mainstay. Current radiocesium levels in Caribou are low (Elkin and Bethke 1995), although levels of polonium-210 (natural source) in Lake Harbour Caribou appear to be slightly higher compared with levels in other herds (Macdonald et al. 1996).

Migratory birds are generally exposed to higher contaminant levels in southern latitudes, but determining exact sources is extremely difficult. Normally, birds like geese, grouse, and ptarmigan do not accumulate high levels of contaminants. Fish-eating birds like mergansers and loons have the highest organochlorine levels (DIAND 1996a).

Organochlorines

Produced for agricultural and industrial uses around the world, many organochlorines are stable and volatile enough to be transported over long distances. Although concentrations are generally lower in the Arctic than in highly polluted areas in southern latitudes, some of the more volatile compounds, such as toxaphene and lindane, can occur in concentrations similar to, and in some cases higher than, those in the regions where they originate. Trends in levels of organochlorines in the Arctic environment vary according to production and use of the various compounds on a global basis. Chlordane and toxaphene use continued well past the DDT ban in 1975.

Chlordane was used as a replacement for DDT throughout the 1970s and was deregistered only in 1988. Recent analyses of PCBs in the Agassiz Ice Cap on Ellesmere Island suggest that the rate of deposition was high in the early 1960s, decreased until the early 1980s, then returned to higher levels in 1990 (Gregor et al. 1995). The major local source of PCBs seems to be associated with Distant Early Warning (DEW) Line sites (Fig. 9.5), where disturbance caused by cleanup activities results in reemission of on-site contaminants into the atmosphere. These local sources contribute negligible amounts to Arctic ecosystems on the whole. Within marine ecosystems, organochlorines generally declined in marine mammals and seabirds during the 1970s (D. Muir, Freshwater Institute, Department of Fisheries and Oceans, personal communication). Other evidence indicates that levels of organochlorines decreased in seabirds but appeared to increase in Polar Bears. Toxaphene and other organochlorines appear to have increased relative to PCBs and DDT in Beluga blubber in the 1980s (Muir et al. 1992). Levels of chlordane have increased in Arctic seabird eggs (Noble 1990).

On a seasonal basis, concentrations of DDT and lindane in Arctic air peak in spring, and levels of toxaphene and PCBs are highest in summer (Han 1994). Migratory patterns of raptors offer evidence of contaminant sources and pathways. Generally, there has been a decline in levels of organochlorines over the last 30 years in Peregrine Falcons (Peakall et al. 1990; Court 1993). Peregrine Falcon eggs have significantly higher (30–70 times) levels of DDT and PCBs than Gyrfalcon eggs; this reflects the fact that Peregrine Falcons winter in Central and South America (where these contaminants occur at relatively high levels) and prey heavily on shorebirds, which are also migratory (Thomas et al. 1992), whereas nonmigratory Gyrfalcons prey on Arctic upland game, such as ptarmigan, lemmings, and hares.

For organochlorines, there seems to be a link between the amount of marine mammal tissue eaten and the amount of contaminants that accumulates in the body tissue of the person who eats the meat. Studies of mothers' milk from Inuit women in northern Quebec show elevated levels of organochlorines, in some cases four to eight times higher than those of women in southern Quebec (DIAND 1996a). In a number of mammal species, including humans, females of reproductive age tend to have lower levels of organochlorine contaminants than males of similar age, because they excrete the organochlorines to their young through their milk (Dewailly et al. 1989). The Quebec study caused concern and led to additional studies, which resulted in no conclusive evidence of health risk associated with consumption of country food (Usher et al. 1995).

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are formed mainly by incomplete combustion of fossil fuels, as well as naturally from forest or brush fires. Many PAHs (e.g., benzo[a]pyrene) become carcinogenic. Although the bioaccumulation potential of PAHs is very low, these compounds are taken up rapidly by marine organisms, such as fish, in which they become transformed into carcinogenic compounds and at high doses can induce tumour formation (Metcalfe et al. 1988; Muir et al. 1992).

Extensive collection of baseline data in the eastern Arctic and southern Beaufort Sea has shown that, as of the late 1970s, Arctic marine waters were clear of hydrocarbons, unlike marine waters in mid-latitudes. Levels of floating particulate petroleum residues were negligible, and PAHs were at levels comparable to those in uncontaminated sites in the northeast Pacific Ocean (Muir et al. 1992). Studies of the deposi-

tion of PAHs in the Agassiz Ice Cap on Ellesmere Island suggest a decline from the high levels prior to 1974–1975 (Peters et al. 1995). PAH levels in Arctic marine mammals and invertebrates are generally low, indicating little contamination in their environment (Muir et al. 1992).

Radionuclides

Within the Arctic, levels of radioactivity in air and average annual fallout of radioactivity have decreased considerably since the 1963 moratorium on weapons testing, when levels in communities and individuals were disturbingly high. Measurements carried out by the Department of National Health and Welfare in 1989–1990 showed a significant decrease to levels that are not considered to be of concern (Thomas et al. 1992; P. Birkwood, Health Canada, personal communication).

New hazards are coming to light with the end of the Cold War and increased information exchange with the Russian Federation. A White Paper released in March 1993 by the Russian government revealed the existence of 16 solid and 14 liquid radioactive waste dumps in Russian Federation marine waters (Gizewski 1993–1994). The radioactivity associated with this dumping is estimated at 2.4 million curies, which is twice the radioactivity that the International Atomic Energy Agency estimates was dumped by all nations during the 1950s and 1960s (Murkowski 1994); however, the radioactive matter is not thought to be very mobile. Added to this is the potential for radioactivity emanating from nuclear effluents discharged to rivers from reprocessing plants, such as the Sellafield plant in the United Kingdom and the plant in Brittany in France. Other potential hazards include future accidents, decommissioning of nuclear sites and facilities, and weapons disposal.

Heavy metals

Although most heavy metals have increased in the Arctic relative to historical times, pinpointing sources is a problem. The existence of distinct geographic trends (e.g., concentrations of cadmium in Ringed Seal and Beluga that increase from west to east; higher mercury in Beluga in the western versus the eastern Arctic) suggests that natural sources are dominant in the marine environment (Wagemann et al. 1996), although these inputs might result from atmospheric deposition. High levels of cadmium have been found in the liver and kidneys of Caribou from the Porcupine and George River herds. In the case of the Porcupine herd, the high levels seem linked to their range being on naturally occurring cadmium–zinc shales.

Part of a review by Health Canada of a 20-year database of analyses of hair and blood samples for mercury levels from over 500 Native communities across Canada (Wheatley 1994) concluded that about 40% of Northwest Territories Aboriginal residents had mercury levels above 20 µg/L in blood, with 1% above 100 µg/L. Between 1972 and 1989, mercury levels were consistently higher in Inuit than in Dene in the Northwest Territories (Wheatley 1995; Wheatley and Paradis 1996). The group of greatest concern is women of child-bearing age. The highest mean levels in this group in Canada were found in Northwest Territories Inuit: over 30% of the women tested had mean mercury levels of 16 µg/g in hair, well into the risk range of 10–20 µg/g as suggested by the World Health Organization (WHO) for fetal exposure (WHO 1990; Wheatley 1995; Wheatley and Paradis 1995, 1996). These elevated levels were linked with the consumption of Beluga and unusually high quantities of Lake Trout. A health advisory was issued advising everyone except pregnant women and women of child-bearing age not to limit their intake of country food (Usher et al. 1995). The influence of dietary and environmental sources of cadmium exposure appears to be minor compared with the contribution from smoking (Benedetti et al. 1994).

Atmospheric change

The Arctic plays a vital role in global climate, acting as a global "heat sink," cooling the air and absorbing the heat transported north from the tropics via global air circulation. Also, the impacts of ozone depletion and a strengthening "greenhouse" effect are likely to be felt more acutely in higher latitudes than elsewhere on Earth (Coward and Hurka 1993).

Global warming

If atmospheric carbon dioxide doubles, warming is predicted in Arctic regions, perhaps as much as 8–10°C in winter (Coward and Hurka 1993; see Chapters 10 and 15). The warming will not be uniformly distributed in space or time. In fact, during the transition period, some areas may actually become cooler than they are now. For example, records for 1946–1993 suggest that the annual mean temperature for the Arctic Cordillera ecozone has declined overall by 1.0°C (consistent with the general cooling of the northwest Atlantic Ocean). In contrast, much of the western portion of the Northern and Southern Arctic ecozones has increased by as much as 0.6°C (consistent with the mid-continent warming that has been observed) (see Chapter 10).

Although these long-term changes appear small compared with seasonal changes, they are significant: for example, the tree line is expected to shift northwards 100 km for every 1°C of annual warming. Under past climate change events, this would likely have occurred more slowly than is projected. The climate models suggest that temperature values will likely change too quickly for a smooth transition to occur. The prospect of long-term warming of the Arctic has led to concern over the possible physical, biological, and socioeconomic impacts that might accompany it. Predictions are that the Arctic ecosystems will be stressed at rates that will produce significant changes. Effects may well include dramatic positive feedback mechanisms as interactions in the Arctic between the oceans, the ice, and the atmosphere impact the mid-latitudes. Although the effects of global warming would at first appear to be beneficial to the Arctic in terms of a less harsh climate and improved accessibility, they could also entail the loss of what makes the Arctic unique — its highly specialized wildlife, the migratory animals that depend seasonally on Arctic habitat, and the culture and lifestyle of its Indigenous people (see Chapter 15 in Government of Canada 1991).

Depletion of the ozone layer

Stratospheric ozone depletion produces an increase in ground-level ultraviolet-B (UV-B) radiation (Kerr and McElroy 1993). Concern over the depletion of stratospheric ozone mainly relates to the damaging biological effects that increased UV-B may have on Arctic ecosystems. This phenomenon is poorly understood, and its implications for Arctic ecosystems have yet to be clearly established (see Chapters 10 and 15 for further information).

Water flow regimes

The Mackenzie (the largest river system in Canada), the Churchill, the Saskatchewan/Nelson, the La Grande, and other river systems drain through the Montane, Boreal, and Taiga ecozones to flow into Arctic marine ecozones. The catchments of these rivers include diverse landscapes associated with intensive agriculture and forestry practices, including spreading of fertilizers and spraying of pesticides. Rivers are used for hydroelectric development and production, water supply, wastewater disposal, pulp and paper production, hydrocarbon exploration and extraction, and mining activities. Rivers act as a transport mechanism and are used for disposal of effluents, potentially contributing significant amounts of nutrients, minerals, and toxic substances that ultimately course into Arctic marine waters (French and Slaymaker 1993).

Diversion schemes as a result of demand for electricity in southern Canadian ecozones have altered the timing and amounts of flows into James and Hudson bays. In the circumpolar context, the Arctic Ocean contains less than 2% of the world's ocean water but receives a disproportionately large fraction of the world's river discharge, collecting about 10% of the total global runoff. This freshwater input contributes to the stratification of the upper layers of the Arctic Ocean and promotes sea ice formation in the winter. Estimates suggest that as little as a 15% change in long-term freshwater input to the Arctic Ocean could impact oceanic currents and influence global climates. The Mackenzie River alone contributes 12% of freshwater input into the Arctic Ocean; 70% is from three rivers in the Russian Federation.

International barriers to sustainable use of biological resources

For Inuit, the Arctic ecozones are more than a source of food and income: their society and culture are based on their relationship with the Arctic environment and, in particular, on harvesting wildlife. This relationship is at the root of the psychological well-being of individuals, the social forms and organizations of communities, and the identity and worldview of the Inuit people.

Inuit are especially vulnerable to domestic and foreign campaigns by animal rights and animal welfare groups to ban fur: they cannot turn to agriculture or industry for a livelihood to replace their trade in wildlife. The anti-seal hunting campaign and the 1983 sealskin ban by the European Economic Community (EEC) basically destroyed the Canadian sealskin market: the value of a pelt dropped from $23 in 1980 to $7 in 1985 (K. Emmett, Government of the Northwest Territories, personal communication), and total numbers sold declined sharply. Although products made of skins from Ringed Seals (the species hunted by the Inuit) were specifically exempted from the EEC directive, the protests triggered a general reaction against all seal products, regardless of species or origin. Within two years of the EEC directive, Canadian Inuit had lost more than three-quarters of their income from sealing and up to one-third of their cash income from all sources (Inuit Circumpolar Conference 1994). Since then, the value of pelts has been rising slowly. In 1995, small quantities peaked at $20 per pelt as a result of the demand from Asian markets (J. Best, Government of the Northwest Territories, personal communication). Individual EEC countries, such as the Netherlands and France, have created their own anti-sealing legislation. In the Netherlands, import of all commercial sealskins is prohibited. In France, there is a species-specific import ban on skins of Harbour Seals, with a general seal product import ban pending in the legislative system. The United States legally protects all seal species, although it recognizes that trade in sealskins is important both culturally and economically to the Inuit of the circumpolar North.

The various bans on sealskin products are not the only international trade barriers that affect the sustainability of the Inuit way of life. There are also barriers that specifically affect the Inuit's international markets for marine and terrestrial mammals.

The U.S. *Marine Mammal Protection Act* (1972) prohibits the import into the United States of any marine mammal product, regardless of whether the harvest is biologically sustainable. Recent amendments allow for the importation of marine products for noncommercial purposes, including the strictly controlled importation of Polar Bears killed in legal trophy hunts in Canada. In Europe, the import restrictions on whale products take their rationale from the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) rules, which are not generally considered trade obstacles. An exception is made for the private consumption of Greenlanders living in Denmark, and Arctic travellers returning to Europe are allowed to bring back artifacts made of marine mammal teeth or bone.

Although the value of fur harvesting has declined in the Arctic (e.g., it has declined by over 70% in the Northwest Territories), sales of fur from terrestrial mammals remain important to the local economies of many communities. The EEC countries intend to prohibit the importation of fur products from 13 different wild fur species, unless the exporting countries forbid the use of leghold traps or trap in accordance with international humane standards (Task Force on Sustainable Development and Utilization 1995a). The European Commission recommended to the EEC that the fur ban be delayed to 1997 (Bremer 1995).

Currently, there are no trade barriers affecting fish and shellfish from the Arctic ecozones (Task Force on Sustainable Development and Utilization 1995b).

Regional issues

Hazardous and special wastes

The disposal of municipal and industrial liquid and solid wastes presents special problems in the Arctic. Wastes do not decompose as rapidly as they do in more southerly locations, and the installation of standard sewage treatment systems is virtually impossible in wetlands, permafrost, and rock. The Arctic Environmental Strategy (AES) has put in place a program to inventory waste sites in northern Canada, to assess associated risks, and to develop protocols for cleaning up military sites and discarded fuel drums. This AES program is being delivered primarily in Yukon and the Northwest Territories, although it includes some research on contaminants in northern Quebec and Labrador. So far, it has cleaned up about 38% of the waste sites inventoried, including 200 hazardous sites. Of the remaining sites, less than 10% have physical or chemical hazards that require remediation (DIAND 1996a).

Municipal wastewater disposal

Recent studies (Heinke et al. 1988; S. Théberge, Ministère de l'Environnement et de la Faune, Gouvernement du Québec, personal communication) in northern Quebec and the Northwest Territories have reported problems associated with waste handling and water treatment facilities. Some communities in northern Quebec have permanent wastewater treatment systems, whereas others have only temporary facilities for the storage of wastewater. In the Northwest Territories portion of the Arctic ecozones, 2 million cubic metres of water are used by communities annually, approximately 105 L per person per day. In 1993, half the 39 communities studied had no treatment, and the remainder had minimal treatment of liquid waste. "No treatment" includes direct discharges through outfall pipes into marine waters, uncontained deposit onto land, or individual disposal systems, such as septic tanks or pit privies. "Minimal" or "primary treatment" includes seepage pits and lagoon systems. Most communities within the Arctic ecozones have waste "stabilization" ponds, and some have sewage lagoons where some bacterial breakdown occurs prior to disposal into the sea, into a large water body, or over the tundra. In a few communities, residence times in primary lagoons do provide limited secondary treatment, but low temperatures throughout much of the year seriously inhibit biological waste breakdown. Lagoons and storage ponds can leak or overflow. For instance, Iqaluit has experienced a series of spills from its storage facility since 1980. The largest occurred in 1991 and involved 1.7 million litres of sewage spilling directly into the ocean. In general, sewage treatment within the Arctic ecozones consists of a primary sewage lagoon with yearly or, in some cases (e.g., Iqaluit), continuous flow to the receiving environment. Other communities (e.g., Resolute) have no treatment and discharge directly to the sea.

Drinking water supply

The contamination of surface drinking water supplies by pathogens from improperly managed sewage is a major concern in the Arctic. Although a water quality monitoring network within the Northwest Territories shows all waters are safe for drinking, fishing, swimming, and aquatic life (DIAND 1995a), recent studies in northern Quebec (S. Théberge, Ministère de l'Environnement et de la Faune, Gouvernement du Québec, personal communication) and the Northwest Territories (Robinson and Heinke 1990) have reported problems associated with waste handling and water treatment facilities. Some have reported outbreaks of gastroenteritis that were thought to be linked to the use of waste pits receiving bagged sewage, also known as "honey bag" wastes, to the lack of maintenance of water tank trucks, and to the use of untreated waters.

Solid waste

Solid waste disposal in Arctic communities is still a problem. Approximately 15 000 t of material are deposited in solid waste sites each year. Currently, over 30 000 t of dry cargo are brought to the communities annually via marine resupply; in addition, an undetermined amount is brought in by air. Little is sent south, as costs are prohibitive. Wastes take years to degrade, and sites are subject to leaching of toxic substances such as lead, cadmium, copper, and zinc; however, there has been little study of this potential hazard.

During the past decade, substantial progress has been made in collection and disposal. Inefficient and poorly maintained community dumps have been slowly replaced by well-designed and efficiently managed modified landfill sites. A 1990 survey by the Government of the Northwest Territories (Heinke and Wong 1990) indicated that the frequency of garbage collection in most communities met the government's minimum requirement of at least twice a week, with only Rankin Inlet at once per week. A few communities still depend on bagged sewage, or honey bags. Of the 30 communities surveyed, Sanikiluaq and Rankin Inlet did not meet the minimum requirement for collection of bagged sewage, and only Pond Inlet, Repulse Bay, and Baker Lake did not collect honey bags separately from other garbage, which is a potential health risk. Since 1980, hygienic conditions have greatly improved in northern Quebec. For example, 14 of the communities now have waste disposal sites.

Ocean disposal

Most communities and resource development activities in the Arctic ecozones are located on the coast. A variety of substances, from scrap metal and old ships to municipal sewage and dredge materials, are routinely and legally disposed of in Arctic waters (Fig. 9.6). Conditions at each disposal site differ. Nine sites in the Arctic marine ecozones were used for ocean disposal between 1987 and 1992, comprising 2% of the total 469 disposal sites throughout Canada.

Dredge materials

Government and industry dredge to ensure the safe operation of ships and barges and to construct infrastructure, such as drilling platforms for oil rigs. Since 1987, dredging in Arctic waters represents about 2% or less of the national total. It includes small-scale maintenance dredging and disposal, such as the construction of a breakwater at Pangnirtung and harbour facilities at Tuktoyaktuk. Total annual quantities of dredged material have not exceeded

300 000 t in any one year since 1986 (GNWT 1994a). Although dredging may have short-term visual impacts, it does not cause significant environmental impact in the Arctic as long as clean dredgeate (i.e., wastes from dredging) is involved. Although it is unlikely that Arctic dredging will significantly increase in the immediate future, the potential for expanded hydrocarbon development exists.

Scrap metal

Small quantities of scrap metal from resource development, mostly various forms of steel, have been disposed of in Arctic waters for at least four decades. Scrap metal and building materials that have little recycling value can be costly to remove, especially from sites where seasonal barge service is not available. Since 1982, 50% of permits issued by Environment Canada for disposal of scrap metal in the ocean have been for Northwest Territories sites. Except for the 56 000 t and 400 t of metal disposed of in 1987 and 1992, respectively, by PanArctic Oil, most permits involved less than 100 t of scrap metal (GNWT 1994a).

The dumping of scrap metal can be a controversial social and political issue. For example, in 1993, in the face of opposition from residents of Resolute and Grise Fiord, a permit to dispose of 400 t of scrap metal from Lougheed Island by dumping it into the ocean was rescinded. Consequently, alternatives to ocean dumping of scrap metal are currently being assessed, such as its transport south in empty cargo ships.

Concerns about the presence in the ocean of scrap made of ferrous metals (e.g., iron and steel) relate mainly to structural hazards to navigation, as well as the chemicals associated with paints and attached debris. Little research has been done on ferrous metals as environmental contaminants, but preliminary results indicate no significant negative chemical impacts and some positive impacts, such as enhanced marine wildlife habitat, if disposal occurs in iron-deficient waters. Iron is an essential nutrient for plant and animal growth, and it is deficient in many samples of Arctic seawater (H.E. Welch, Department of Fisheries and Oceans, personal communication).

Figure 9.6
Occurrence of ocean dumping in the Canadian part of the Arctic Ocean, 1983–1993

Source: 1995 National Compendium on Monitoring at Ocean Disposal Sites, Marine Environment Division, Environment Canada.

Mining

Exploration is now the least intrusive mining activity (Milburn et al. 1994), as it is increasingly done from the air, without temporary camps on the permafrost. Operating mines can be local sources of contaminants as a result of exposure and weathering of ore, tailings, and waste rock and release of by-products of mineral extraction, such as arsenic. However, the total mine surface lease area is relatively small — less than 30 km^2, or 0.001% of the total area of the Arctic ecozones. As a result, the impact on the environment from mining itself is limited to a relatively small area; negative impacts are more likely to result from mining infrastructure, such as road links. Accidental spills are also a concern (see section entitled "Spills"). Closure and reclamation of mine sites are now regulated to reduce environmental impacts. For sites that were shut down prior to the introduction of regulations, adequate maintenance of tailing ponds and disposal of mine tailings are potentially serious issues.

Few studies of metal contamination around mine sites have been completed, and little is known of the local and long-range effects (Thomas et al. 1992). To address the need to immobilize the contaminants in mine tailings, the Department of Indian Affairs and Northern Development and the mining industry have installed weather stations at exploration sites and mines in the Northwest Territories for site-specific evaporation studies (DIAND 1996b). Through the cleanup of tailing pond wastes at the abandoned Rankin Inlet nickel mine, an efficient technology was developed that uses a chemical agent to bind elemental nickel, considered an environmental risk (DIAND 1996b). Although there is no agreement on whether ocean disposal poses less of a threat to the environment than land disposal, current research under the Mine Environment Neutral Drainage Program indicates that underwater disposal can be successfully used to control acid rock drainage under certain conditions (R. Tupper, Office of Environmental Affairs, Natural Resources Canada, personal communication).

Drilling

The practice of disposing of waste drilling fluids into land sumps from hydrocarbon activities is a potential source of contaminants, although the disposal of drilling fluids and wastes (offshore and onshore) is strictly regulated. Drilling wastes contain common metal salts (containing zinc, chromium, iron, mercury, and cadmium, as well as potassium, chlorine, and sodium), surface-active substances (e.g., detergent), and petroleum products.

Spills

Between 1972 and 1991, about 100 accidental spills of more than 100 000 L each, involving almost 130 million litres of various liquid wastes or toxic materials, were reported in the Arctic. The bulk of this (83%) was spilled into freshwater or terrestrial ecosystems (National Spill Database, Environmental Protection Service, Environment Canada). From 1990 to 1994, there were over 70 spills per year within communities, averaging approximately 900 L per spill.

During 1972–1991, mine tailings were the single largest type of accidental spill material in the Arctic (National Spill Database, Environmental Protection Service, Environment Canada). Spills of hydrocarbons are the second largest. Many vehicles and generators run on diesel fuel, and large volumes are stored. In 1991, in the Northwest Territories portion of the Arctic ecozones, about 80 million litres of petroleum products were delivered to communities. Most of this arrives by sea; when a loaded tanker is severely damaged by ice, contamination can be extensive.

Tourist activities

The harsh climate and limited winter daylight once restricted tourism to a very short summer season. Today, tourism has expanded to the other three seasons as visitors come to experience dog team excursions, see the northern lights in winter, and experience the flow edge in spring. The Arctic's geography is both its major tourism asset and its major liability, because of the high cost of transportation. Its fragile ecosystems attract tourists but are more vulnerable to their activities than southern ecosystems, which have greater biological productivity and recover more quickly from disturbance. The number of visitors to remote Arctic ecosystems is increasing rapidly, and no one knows the damage threshold. A visitor to the Arctic may have considerable negative impact on the environment (Johnston and Madunic 1995).

At present, most tourist activities are focused on existing settlements and semi-developed areas such as national park reserves (sites held for proposed national parks). However, tourists also travel through remote areas, especially along Arctic canoe and cruise ship routes, and their visits to historic and archaeological sites and to polynyas, shoreleads, and other sites that are important to wild plants and animals (Box 9.1) cannot be regulated.

Problems are associated with campsites, particularly with garbage, environmental damage at heavily used sites, and disturbance to wildlife. On the Firth River in Yukon's Ivvavik National Park, it has already become necessary to limit the number of rafting expeditions. Staff at Auyuittuq National Park Reserve are contemplating a visitor impact study to determine if similar restrictions are necessary for the Akshayuk Pass hiking trail. Encounters with bears attracted to campsites may result in injuries or death to either party. For some subpopulations of bears, losses of even small numbers of animals could put populations into a state of serious decline.

Tourism can be expected to increase as areas with wildlife aggregations, spectacular scenery, remote Inuit communities, or historic sites become better known. For example, in 1992, the Russian ice-breaker *Kapitan Khlebnikov*, carrying 52 passengers, ventured farther north into the Canadian Arctic than any ship in history. Equipped with a helicopter and a fleet of Zodiacs (inflatable boats), the cruise ship sailed along the coast of Ellesmere Island, and its passengers visited inland sites, such as the fossilized forest at the Geodetic Hills and sites within the Ellesmere National Park Reserve (Marsh and Staples 1995).

Cruise-based tourism has the potential to affect the marine and terrestrial Arctic environments more substantially than other forms of tourism. Given the hazards of weather conditions, polar pack ice, and the lack of navigational aids, and given the importance of a relatively few feeding areas to marine animals, the potential for harm to wildlife in marine ecosystems is large and comes from a variety of sources, ranging from uncontrolled waste disposal to disastrous fuel spills.

Military activities

During the 1950s, a North American early-warning system to counter a surprise attack from the Soviet Union was built in Alaska and Canada's North. It comprised three radar systems: the Pinetree Line, completed in 1954, and the Mid-Canada and DEW lines (Fig. 9.5), completed in 1957 (Bone 1992). In 1985, as military activities increased during the Cold War, the United States and Canada agreed to replace the outdated DEW and Pinetree lines with the North Warning System (NWS), consisting of long- and short-range radar sites.

Decommissioning military radar sites

Of the first three radar systems, the DEW Line was the largest construction project, with 42 stations in Canada. In 1957, the significance of these radar sites as a point source of contamination was not known. At that time, wastes, including military wastes, were either allowed to sink through melting ice into lakes or the sea or buried in pits on land. In 1963, every second radar station on the DEW Line site was abandoned. A survey in 1985 identified a variety of wastes at these decommissioned sites, including waste oils, aviation and diesel fuel, PCB-containing transformers and capacitors, solvents, chlorofluorocarbons (CFCs), and lindane. PCBs were identified as the most environmentally significant waste, with an estimated 5 000 L of PCB-containing liquids removed from the sites (Thomas et al. 1992).

In 1989 and 1990, as part of the process of converting DEW Line sites to NWS sites, the departments of National Defence and Indian Affairs and Northern Development studied active and abandoned sites to address short- and long-term environmental problems (Reimer 1991). All violations were cleaned up at that time (R. Hurst, Department of Indian Affairs and Northern Development, personal communication). In total, 863 soil, 125 water, and 324 plant samples were analyzed for inorganic elements (primarily metals), PCBs, acid/base/neutral extractable organic compounds, and volatile organic compounds. Background concentrations were also measured for comparative purposes. PCBs and inorganic elements (metals) were the most prevalent contaminants. The major source of contamination appeared to be waste disposal, given the high levels of both inorganic elements and PCBs found in sewage outfalls and lagoons.

In 1994, the Department of Indian Affairs and Northern Development cleaned up the abandoned DEW Line site at Horton River, N.W.T., the first of 21 for which it is responsible (DIAND 1996a). It removed more than 800 barrels containing oil, fuel, and grease (some leaking sludge onto the tundra), the contents of two 90 920-L fuel storage tanks, and a gravel conveyor. PCB-contaminated materials, including soils, were transported to the Hazardous Waste Disposal Site in Alberta.

Primarily as a result of the presence of PCBs, the soil at some DEW Line sites will undergo further cleaning. Negotiations are under way with the U.S. government for environmental remediation of the sites. Most construction material at these sites is wood, steel, and concrete, with small quantities of nonferrous metal. Although the material represents little hazard as a toxic waste (Reimer 1991), it is unsightly, and disposal can be a problem because of the quantities involved, as well as the desire of Aboriginal peoples to avoid burial of wastes.

Contamination is not limited to DEW Line stations. The Pinetree Line site at Saglek Bay in northern Labrador experienced two major spills of fuel oil in 1974–1975 and another two major spills in 1984–1985: residual cleanup problems persist after a major cleanup and removal of PCBs in 1989. In 1995, major cleanups also occurred at former military installations at Iqaluit, Pearce Point, and the abandoned weather station at Isachson (DIAND 1996a).

Initiatives Towards Sustainable Development

The challenges for sustainable development in the Arctic are many. They include protecting the option of pursuing a traditional Aboriginal lifestyle, facilitating the move to a more cash-based economy, and ensuring that economic development and growth of populations are sustainable and do not harm Arctic ecosystems. The traditional dependence of Aboriginal peoples on the land and its resources forms the basis of their society, culture, and economy. Change is occurring rapidly, most notably through Aboriginal land claims. This change provides unique opportunities for the integration of environment, economy, and social/cultural considerations in all phases of decision-making. Much is now being accomplished in mitigating environmental problems, providing economic benefits to northerners, and involving Aboriginal peoples in the decision-making process, but a great deal more remains to be done.

Concern for the environment remains high, and a number of initiatives are under way at the international, territorial, and community levels. Some examples are listed below; others are described in Chapter 13.

International initiatives

Two major issues face circumpolar nations today, particularly the Russian Federation: environmental cleanup, and ensuring that future development is sustainable (Fenge 1994). Governments of the Arctic states in cooperation with Indigenous peoples are implementing various initiatives, such as the AEPS. These complement initiatives to foster scientific cooperation and sustainable development in the circumpolar region, such as the proposed Arctic Council and the appointment of Canada's circumpolar ambassador (Box 9.5).

Arctic Environmental Protection Strategy

The Arctic's ecosystems are shared by eight countries: Canada, Denmark (Kalaallit Nunaat), Finland, Iceland, Norway, Sweden, the Russian Federation, and the United States. These countries recognize that ecosystems and environmental threats do not respect national boundaries and that collective action will be more effective than the actions of an individual state. On 14 June 1991, ministers from the eight Arctic countries signed a declaration on the protection of the Arctic environment, thereby endorsing the AEPS. Aboriginal organizations helped in preparing the strategy and were accorded observer status. The AEPS represents a collective approach to protecting, enhancing, and restoring the Arctic environment and using natural resources in a sustainable fashion (DIAND 1995b).

The AEPS focuses on four issues: protection of the marine environment, emergency preparedness and response, conservation of flora and fauna, and monitoring and assessment of contaminants. In 1993, the eight ministers set up an Indigenous Peoples' Secretariat to facilitate communication and enhance the participation of Indigenous peoples in the AEPS, and they established a Task Force on Sustainable Development and Utilization. The Task Force is looking at international trade barriers and proposing solutions to the anti-fur legislation proposed by the European Union (Task Force on Sustainable Development and Utilization 1995b). The Arctic Monitoring and Assessment Programme has looked at pollution issues identified in the AEPS and is drafting a protocol for the international control of persistent organic pollutants under the Convention on Long-Range Transboundary Air Pollution of the United Nations Economic Commission for Europe.

Inuit Circumpolar Conference

The Inuit Circumpolar Conference (ICC) was founded in 1977 to help promote Inuit rights and interests internationally and to

ensure the protection of the circumpolar Arctic through a strong joint commitment to sustainable development. Since 1993, when the Inuit of the Russian Federation joined the ICC, the organization has included all 125 000 Inuit of circumpolar countries (Denmark/Kalaallit Nunaat, Canada, United States, and the Russian Federation) (Fenge 1994). To promote circumpolar sustainable development, a comprehensive Arctic policy document was published in 1992 (Inuit Circumpolar Conference 1992). The policy addresses Inuit concerns about peace and security, the environment, the economy, education, and science, as well as social and cultural concerns. This document — along with the ICC's Inuit Regional Conservation Strategy, implemented since 1986 — provides guidelines for sustainable development in the Arctic, for use by circumpolar nations and other organizations, as a foundation upon which Inuit culture can be sustained.

Agreement on the Conservation of Polar Bears

The Polar Bear is one of the few large carnivores left that still occurs throughout most of its historical range. In response to concern that rapidly increasing levels of recorded Polar Bear harvest might result in the wildlife species becoming endangered, five circumpolar countries signed the Agreement on the Conservation of Polar Bears in Oslo in 1973. The agreement came into effect in 1976 and was reaffirmed by Canada, Denmark, Norway, the Soviet Union, and the United States in 1981 (Prestrud and Stirling 1994). The primary goal is to protect the Polar Bear by limiting hunting to sustainable levels.

In the 20 years since the signing, there have been major reductions in the size of reported Polar Bear kills throughout the circumpolar ecosystem where harvesting is allowed. Several Polar Bear populations have recovered to former levels because of the agreement and because most of their original habitat is intact and remote (Prestrud and Stirling 1994). In 1993, the world population of Polar Bears was estimated to be between 21 470 and 28 370 animals.

The Polar Bear agreement has often been cited as one of the most successful Arctic international agreements (Task Force on Sustainable Development and Utilization 1995a). It has been the greatest single influence on the development of internationally coordinated management and research programs that have ensured the survival of Polar Bears to date, such as the establishment of protected areas for Polar Bears in the North and East Greenland National Park and the Melville Bugt Game Preserve in Kalaallit Nunaat (Prestrud and Stirling 1994). The three largest Polar Bear denning areas are all protected. They are located throughout the circumpolar ecosystem at Wrangel Island (Russian Federation), on Kong Karl's Land at Svalbard (Norway), and in western Hudson Bay (Canada).

Arctic Goose Joint Venture

Most geese in North America nest and raise their young in Arctic and sub-Arctic regions of Canada. In order to facilitate goose conservation, monitoring, and research, an Arctic Goose Joint Venture was initiated in 1986 as a component of the North American Waterfowl Management Plan (NAWMP). This cooperative effort by the governments of Canada, the United States, and, more recently, Mexico has led to programs that monitor the status and productivity of Arctic geese, ensure important habitats are protected, and maintain goose populations.

The plan establishes population goals for 26 populations of five goose species. Canada Geese are widely distributed across the continent. The four other species of goose nest exclusively in the Arctic, wintering along both coasts and in the southern United States and Mexico. Eight populations have exceeded NAWMP population targets. Other Arctic goose populations are stable or increasing towards NAWMP goals within the Arctic (Environment Canada 1995).

Box 9.5
Other circumpolar initiatives

Arctic Council

Consensus was reached in June 1995 on the need to create an Arctic Council by representatives of the eight Arctic countries — Canada, Denmark (Kalaallit Nunaat), Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States of America; and of the three Aboriginal peoples' organizations — Inuit Circumpolar Conference, the Saami Council, and the Indigenous Minorities of the North, Siberia, and the Far East of the Russian Federation. A declaration is being prepared to establish an intergovernmental forum for consultation and cooperation on Arctic issues in 1996. At the initial stage, the two main pillars of the Arctic Council will be environmental protection through the AEPS and sustainable development in its broadest sense, including health, economic, social, and cultural issues.

Circumpolar ambassador

Mary Simon was appointed as Canada's first circumpolar ambassador in October 1994. The ambassador reports to both the Minister of Foreign Affairs and the Minister of Indian Affairs and Northern Development and has the following responsibilities:

- *to represent Canada at international meetings on circumpolar issues;*
- *to consult with Canadian northern governments and Aboriginal groups; and*
- *to coordinate Canadian government efforts on circumpolar issues, such as Canada's participation in the AEPS, the implementation of the Canadian initiative to create an Arctic Council, and Canadian policy with respect to Antarctica (DFAIT and DIAND 1994).*

National initiatives

Arctic Environmental Strategy
The federal government launched the $100-million, six-year AES in 1991. The strategy is one of the primary federal vehicles for promoting sustainable development in the Canadian Arctic. Its goal is to preserve and enhance the integrity, health, biodiversity, and productivity of Arctic ecosystems for the benefit of present and future generations. It has four key components:

- *Contaminants*: The Northern Contaminants Program, aimed at reducing and, where possible, eliminating contaminants in country foods, has helped to identify the long-range transport of pollutants as a major source of contamination. A comprehensive assessment of contaminants in Arctic ecosystems and their effects on the consumption of traditional foods is now in progress. More than 100 research projects, designed to answer questions about sources, pathways, and sinks of the various environmental contaminants — where they go in the ecosystem, and what the current exposure levels are in wildlife and human populations — have been conducted, with the full participation of northerners.
- *Waste*: The goal of this program is to eliminate hazardous and unsightly material and equipment abandoned in the North. About 900 waste sites have been identified, and more than 400 have been cleaned up. Aboriginal and community groups have lent support, and local contractors have been employed in a large number of the projects. Two major projects were cost-shared with Environment Canada's National Contaminated Sites Remediation Program, for a total federal allocation of $3.9 million. About one-third of those funds were devoted to the assessment of DEW Line/NWS sites, and another third to remediating tailings at the abandoned nickel mine at Rankin Inlet.
- *Water*: This component has developed a comprehensive aquatic ecosystem program that combines water quality, water quantity, snow contaminant, and biological monitoring subprograms in both territories. The program responds to local, Aboriginal, and industrial concerns about the productivity, health, and safety of northern aquatic ecosystems. Over 100 monitoring stations have been built to assess water quality and quantity. Another AES initiative has been the Northern Aquatic Food Chain Contamination Database, to help manage the extensive data being generated in recent years and make them readily accessible to researchers in the Canadian Arctic and Kalaallit Nunaat. Data distribution began in early 1994.
- *Environment/economy integration*: This program promotes cooperative, short-term projects at the community level that will provide long-term environmental and economic benefits. Projects that develop and use traditional values, knowledge, and resources are emphasized. More than 45 northern communities have designed and carried out their own environmental action projects, such as commercial fisheries and ecotourism.

Conservation strategies
In response to recommendations of the World Commission on Environment and Development (1987) and two Canadian task forces — the Task Force on Northern Conservation (1984) and the National Task Force on Environment and the Economy (1987) — the need for integrated management of marine resources was identified. Implementation of their recommendations was the responsibility of a working group on northern conservation strategies, made up of federal and territorial governments, ICC, and Indigenous Survival International. This group laid the foundation for the development of four major conservation strategies: the Arctic Marine Conservation Strategy (Department of Fisheries and Oceans), the Inuit Regional Conservation Strategy (ICC), the Yukon Conservation Strategy (Government of Yukon), and Endangered Spaces (World Wildlife Fund Canada and the Canadian Parks and Wilderness Society).

The focus of this work was to promote conservation in Yukon, the Northwest Territories, the Arctic seas, Labrador, and northern Quebec, with a view to the development of a circumpolar strategy. The goal was to integrate community, regional, territorial, national, and international interests.

Regional initiatives

To be successful, strategies for sustainable development in the Arctic ecozones require the full participation of the Inuit. Apart from the Inuit of Quebec, whose claim to the offshore islands in Hudson Strait and Hudson and Ungava bays was not covered under earlier claim settlements and remains outstanding, the Inuit of Labrador are the only Inuit who have not settled their outstanding Aboriginal land claims. Labrador Inuit believe that the only hope for environmental protection and responsible management of resources in northern Labrador is a land claim settlement based on the same basic principles as the Nunavut Land Claims Agreement. Land claim agreements set the stage for a move towards more local control over resources and the development of comanagement arrangements (i.e., boards or commissions to jointly manage natural resources) between Inuit and governments.

Land claims and comanagement
The Arctic ecozones include two complete land claim settlement areas and portions of other settlement areas (Fig. 9.4). For the portions of the Sahtu Dene and Gwich'in land claim settlement areas, see Chapter 8 for further information. Settlement legislation for the Inuvialuit Final Agreement was passed in 1984 and for the Nunavut Land Claims Agreement in 1993 (Box 9.6). Under each claim, various comanagement bodies with extensive powers have been established to manage natural resources. Government must consult with and take advice from comanagement boards, composed of Aboriginal and government representatives, on a wide range of environmental issues.

- *Inuvialuit comanagement*: Under the Inuvialuit Final Agreement, there are two Wildlife Management Advisory Councils advising on wildlife management, one for the Yukon North Slope and one for the Northwest Territories portion of the Inu-

vialuit Settlement Region; the Fisheries Joint Management Committee, which manages access to fisheries, carries out research of populations, and allocates fisheries in both the Northwest Territories and Yukon North Slope portions of the Inuvialuit Settlement Region; and the Research Advisory Council, which commissions, collects, collates, and is the repository for research data, so that better-informed decisions can be made relating to wildlife and the environment.

- *Nunavut comanagement*: In the Nunavut Land Claims Agreement, there are provisions for the establishment of the Nunavut Planning Commission (see next section); the Nunavut Impact Review Board; the Nunavut Water Board, which will regulate the use and management of water; and the Nunavut Wildlife Management Board, which will study and advise on issues related to wildlife (including fisheries) and allow beneficiaries of the agreement to play an effective role in all aspects of wildlife management within the settlement area. At present, transition teams are working to put operating procedures in place for the boards, which will come into force in July 1996.

- *Northern Quebec comanagement*: The James Bay and Northern Quebec Agreement (1975) boasts the oldest comanagement arrangement in Canada. It was followed by the Northeastern Quebec Agreement signed in 1978. The James Bay Hunting, Fishing and Trapping Committee advises on wildlife management. Inuit are represented on two environmental protection committees — the Kativik Environmental Quality Committee, responsible for the evaluation and analysis of environmental development projects, and the Kativik Environmental Advisory Committee (T. Beaudet, Ministère de l'Environnement et de la Faune, Gouvernement du Québec, personal communication).

Approximately 17% of the lands in Nunavut, which falls within the Arctic ecozones, are now under the collective private ownership of the claim beneficiaries. Claim beneficiaries are now partners with government in the management of northern natural resources. The Northwest Territories will be divided (along the western Nunavut boundary) in 1999, with a fully operational Nunavut government in place by 2008.

Regional land use planning in the Nunavut land claim area

The Northern Land Use Planning Program, which applied to the whole of the Northwest Territories and Yukon, was a cooperative effort of the federal and territorial governments and Aboriginal organizations that was terminated in 1991. Under that program, two regional land use plans were initiated in the Nunavut claim area (Nunavut Planning Commission Transition Team 1995).

The Lancaster Sound Regional Land Use Plan, approved in 1990, provides direction for government, industry, and communities on the use of 1.5 million square kilometres of the Arctic ecozones. Although the Lancaster Sound Planning Commission decided against allocating land uses to particular areas, on the basis that it was premature to do so, the commission ranked and mapped the entire planning area according to its importance to the five communities and to wildlife.

The Keewatin Regional Land Use Plan, approved in 1994 and applying to a 705 000-km^2 planning region, including the communities of Arviat, Baker Lake, Chesterfield Inlet, Coral Harbour, Repulse Bay, and Whale Cove, is structured much like the Lancaster Sound plan. The planning region includes the Beverly and Qamanirjuaq Caribou herds, the Thelon and Kazan Canadian Heritage Rivers, and the proposed Wager Bay National Park. It is also a region of significant mineral exploration.

Box 9.6
The Nunavut Land Claims Agreement

The Nunavut Land Claims Agreement, covering an area of approximately 1.9 million square kilometres, is the largest land area treaty ever signed in Canada. By accepting its 41 articles, the Inuit have agreed to exchange Aboriginal rights to all lands and waters for defined rights and benefits, including ownership of 350 000 km^2 of land and the mineral rights on about 10% of it. The Nunavut Land Claims Agreement is far more detailed than the James Bay and Northern Quebec Agreement and the Inuvialuit Final Agreement. It requires the creation of new natural resource management institutions with significant decision-making powers, in which Inuit are guaranteed 50% membership. In contrast, the Inuvialuit Final Agreement gives the Inuvialuit a strong advisory role in environmental management.

The greatest difference between the Nunavut Land Claims Agreement and other northern comprehensive land claim agreements lies in the provisions for political development in Nunavut. As a requirement of the Nunavut Land Claims Agreement, the Government of Canada will recommend to Parliament legislation to establish a new Nunavut Territory in 1999, with its own legislative assembly and public government, separate from the government of the remainder of the Northwest Territories.

Provisions of Article 5, Wildlife, of the Nunavut Land Claims Agreement give the Inuit a legal right to harvest throughout Nunavut, reflecting the fact that wildlife will continue to provide the basis of a viable resource economy for Inuit in the future. The provisions give priority in the allocation of harvesting quotas first to personal consumption, then to hunters' and trappers' associations and to regional wildlife organizations for the development of commercial enterprises based on wildlife harvesting. Inuit organizations will have the right of first refusal in establishing new lodges for recreational hunters and fishermen and naturalists; in establishing operating facilities for animal husbandry; and in the marketing of wildlife, wildlife parts, and wildlife products. Complementing the system of wildlife management will be a system of environmental management that will play an essential role in providing long-term environmental protection for the wildlife harvesting and renewable resource economy.

Nunavut Tunngavik Incorporated, the Government of the Northwest Territories, and the Government of Canada have made interim arrangements to guide land use planning in the land claim area until the Nunavut Planning Commission is established. Preplanning is under way in the West Kitikmeot planning region, using a community-based planning process that will provide a valuable basis for decision-making, environmental protection, and resource management in the new territory. When the new territory is established (July 1996), the Nunavut Planning Commission will prepare guidelines on how the land is to be used, including industrial development and conservation.

Protected areas

A protected area network is a principal step in ensuring the continued viability of Arctic ecosystems. Protected areas (IUCN[1] categories I–VI) within the Arctic ecozones comprise nearly 18% of the Arctic Cordillera, about 3% of the Northern Arctic, and approximately 22% of the Southern Arctic. This accounts for a total of 281 336 km^2, or about 11% of the Arctic ecozones. No marine conservation areas have been established to date.

The area under protection increased very little between the 1980s and the 1990s. The settlement of land claims slowed the pace of protected area establishment. The Inuvialuit Final Agreement of 1984 established Ivvavik National Park within the settlement region. Legislation is pending for Pingo Canadian Landmark and a 1992 agreement to establish the 21 500-km^2 Aulavik National Park on Banks Island. Settlement of the Nunavut Land Claims Agreement in 1993 paved the way for the establishment of parks and other conservation areas. The legislation set the time frame for establishment of three national parks in the eastern Arctic — Auyuittuq National Park Reserve on Baffin Island (national park status pending), Ellesmere Island National Park Reserve (national park status pending), and the proposed North Baffin National Park (27 252 km^2) (July 1996). Three other national park initiatives are under way: Wager Bay and Northern Bathurst Island in the Northwest Territories, and Torngat in Labrador. Land has also been set aside for Tuktut Nogait, N.W.T. (28 190 km^2), which includes part of three claims areas; the purpose of the park is to protect calving areas of the Bluenose Caribou herd. There are five proposed provincial park reserves set aside within Arctic Quebec under the Quebec Provincial Parks Action Plan (1992–1997) (C. Potvin, Ministère de l'Environnement et de la Faune, Gouvernement du Québec, personal communication).

Nongovernmental organizations (NGOs) have been active in pressing not only for additional protected areas in the Canadian Arctic, but also for an international system of large-scale protected ecosystems in terrestrial and marine areas of the circumpolar Arctic. The system proposed by the NGOs to the Conservation of Arctic Flora and Fauna International Working Group would include the "Arctic Ring of Life" International Marine Biocultural Reserve, the Bering Sea Ecosystem, the Caribou Commons Biocultural Reserve, Beringia Heritage International Park, and the proposed Isabella Bay Biosphere Reserve.

Local initiatives

Of particular significance are initiatives undertaken by the communities themselves. Grise Fiord residents were the force behind the nomination of Coburg Island, which is the site of a huge seabird colony, as a National Wildlife Area. The area will be known as Nirjutiqavvik National Wildlife Area. The community of Clyde River has proposed the creation of Igalirtuuq National Wildlife Area to protect important Bowhead Whale habitat at Isabella Bay, Baffin Island (Box 9.7). The area is expected to form the core of a biosphere reserve. Arviat and Baker Lake have initiated the designation of national heritage sites, as have Cape Dorset and Pond Inlet.

Community conservation plans have been completed by each of the six communities in the Inuvialuit Settlement Region. Pioneering work has also been undertaken by Sanikiluaq on the Belcher Islands in Hudson Bay towards developing an integrated resource management plan. The Labrador Inuit Association and Inuit Tapirisat of Canada have a joint project to collect information on community waste management.

Traditional ecological knowledge

Over many generations, the Inuit have developed in-depth knowledge of the ecosystems in which they live. As hunters, they occupy the same ecosystems as their prey, and accurate observations and interpretations about wildlife behaviour, weather patterns, and other environmental factors are needed in order to survive. Inuit traditionally spend hours on the land and, hence, have the opportunity to become very familiar with their surroundings. Lessons are learned, and the knowledge base becomes fine-tuned with experience. A specialized vocabulary has developed. This field of ecological knowledge or expertise is commonly known as "traditional ecological knowledge" (Box 9.8).

The Inuit hunters' understanding of their environment and the skills and knowledge that they need to survive in it are built on associations between themselves, the land, the sea, and the wild animals. A basic tenet of Inuit culture is that humans and other animals are equals and that all have souls and spirit powers. This respect for wild animals has allowed the Inuit to hunt, trap, and fish in a way that conserved populations for future generations. In Labrador, for example, the Inuit have many rules that ensure that species are not overharvested, including rules prohibiting the killing of animals during their breeding season. "Ningiqtuq," or sharing, has always been an important feature of Inuit culture and ensures that food reaches everyone, especially elders unable to hunt for themselves. This informal system of allocating resources is a vital socioeconomic tool, providing everyone with access to food and the material resources of the community.

The passing of knowledge from one generation to the next and the teachings by elders have resulted in a huge reservoir of

1. International Union for the Conservation of Nature and Natural Resources, now known as the World Conservation Union.

information that is helping to guide the development of the sharing philosophy, to shape laws and customs, and to promote the value of sustainable living. An example of the integration of traditional and scientific knowledge is the Hudson Bay Programme, initiated in 1991 by the Canadian Arctic Resources Committee, the Environmental Committee of Sanikiluaq, and the Rawson Academy of Aquatic Science to assess the cumulative impacts of human activities on Hudson and James bays. Scientific knowledge on the Common Eider and other birds of the Hudson and James bay ecosystems is extremely limited. Inuit hunters from Sanikiluaq, Inukjuak, and Kuujjuarapik provide detailed observations for the entire annual cycle of the Common Eider over an extensive region, contributing incidental observations to the scientific knowledge of the Hudson Bay subspecies. Inuit hunters recognize seven distinct categories of Common Eider according to criteria of age and sex, each category bearing a unique name. Important ecological relationships have been identified, such as eider distribution and ice movement, winter mortality and eider age, nesting success and fox occurrence, and physical condition and seasonal changes in diet. The hunters' observations on the overwintering of the Common Eider on ice-covered Hudson Bay are unique and integral to a complete understanding of the species' ecology.

CHALLENGES FOR SUSTAINABLE DEVELOPMENT

Current status

In the Arctic ecozones, the small human population is widely dispersed, and development, including extraction and primary industries, is largely absent. So far, the severe climate and remoteness of the area and concomitant high cost of extraction have prevented much development of the area's base metals, uranium, and oil and gas. However, each year there is an increasing awareness of the resource potential of the North. Tourism is also increasing, and no one knows how much of an increase in tourist traffic it would take to pose a threat to the environment.

Box 9.7
From a community-based concern to a UNESCO biosphere reserve

The Bowhead Whale population in the Davis Strait–Baffin Bay region was severely depleted by commercial whaling during the 18th and 19th centuries. Although whaling ceased by 1915, the population, which once numbered about 11 000 (Finley 1990), has not recovered and now numbers only a few hundred whales. The Inuit have a centuries-old tradition of hunting the bowhead. Apart from its value as part of the subsistence economy, the bowhead plays an important role in the Inuit culture. The people of the area, the Ukkumiut, want bowhead populations to recover so that they can resume their traditional hunt. The Inuit have extensive knowledge of the bowhead and know a great deal about the habits and distribution of marine mammals in Baffin Bay. On the other hand, there is very little information on the species in the scientific literature.

When Kerry Finley, a scientist, visited the area in 1979 in connection with proposed offshore hydrocarbon exploration, an Inuk hunter from Clyde River (Kangirtugaapik) on the east coast of Baffin Island told him of summer concentrations of Bowhead Whales in Isabella Bay (Igalirtuuq). That casual encounter between scientist and hunter led to a decade of community participation in scientific studies of the whales and the development of a community-based conservation strategy for the protection of the Bowhead Whales and their critical habitat at Isabella Bay. The biological research project at Isabella Bay began in 1983 as a collaborative effort of the Hunters and Trappers Association of Clyde River, World Wildlife Fund Canada, and territorial and federal governments. In 1988, the community met and resolved to develop a conservation plan for Isabella Bay. The Igalirtuuq Steering Committee was formed by the Hunters and Trappers Association and community members and in 1990 submitted its proposal — Igalirtuuq: a conservation proposal for Bowhead Whales at Isabella Bay, Baffin Island — to the territorial and federal governments. Since that time, the steering committee has worked closely with a working group of government officials and regional Inuit organizations to develop a consensus on how to implement the proposal. The proposal was the first study funded by the federal Community Resource Management Program of the AES. It was concluded that a national wildlife area should be established to form the protected core area of a larger United Nations Educational, Scientific, and Cultural Organization (UNESCO) biosphere reserve.

In 1993, Clyde River held a plebiscite on the proposal, and 93% voted in favour of the proposed conservation measures. Plans have been developed that will ensure the direct participation of the community in the management of the national wildlife area and biosphere reserve once they have been formally established. To date, all of the original objectives are being met. In addition, the community has benefited economically from its participation in scientific research activities.

The success of this community-based initiative is a reflection of the close-knit nature of the community and the opportunity everyone had to become informed and involved in their own language. It is also a reflection of the close working relationship between the research scientist, World Wildlife Fund Canada staff, government officials, and the community and of the recognition and use of local, traditional, and scientific knowledge. The process has taken over 10 years so far. It has involved many organizations, Inuit, and governments, and it had to be reviewed in the broader context of regional land use planning and land claims. Deliberations were time consuming and often difficult. The process demanded considerable patience from all concerned and a willingness on the part of each organization to see it through to a successful conclusion. The area is expected to be officially established as the Igalirtuuq National Wildlife Area by 1996 and has been proposed as an international biosphere reserve.

The absence of an extensive environmental database, the limited scientific understanding of the interrelationships of ecosystem components, and the inadequate integration of Indigenous environmental knowledge with other forms of understanding are widely recognized. The limited database is in general a result of the low priority placed on Arctic environmental research, the high cost of obtaining this information, and development pressures on the region. In contrast, the absence of integration of traditional knowledge with other information is largely a cultural problem resulting from the exclusionary nature of modern science. Together, these gaps prevent effective assessment of the impacts of development.

Since 1991, scientific knowledge of contaminants has improved tremendously. Data on spatial trends in Arctic terrestrial ecosystems have increased, most notably for organochlorines and heavy metals in Caribou and waterfowl. Knowledge of spatial trends in Arctic freshwater fish and Arctic marine ecosystems has progressed, especially for heavy metals in Ringed Seals and organochlorines in Polar Bears (D. Muir, Freshwater Institute, Department of Fisheries and Oceans, personal communication).

The most significant gap in contaminant information is the lack of temporal trend information for organochlorines and metals. The information currently available is still limited. Although over 100 organochlorines and 25 metals have been monitored over the past five years, there are still some groups of substances (e.g., metals in terrestrial ecosystems) for which information on spatial trends is limited. Databases for lower marine food chains are limited (D. Muir, Freshwater Institute, Department of Fisheries and Oceans, personal communication).

Box 9.8
Traditional ecological knowledge

"Traditional ecological knowledge" (TEK) is defined as the knowledge acquired by Indigenous or local peoples through generations of direct contact with the environment. This is also referred to as TEKMS (traditional ecological knowledge management systems), Indigenous knowledge, traditional knowledge, Indigenous environmental knowledge, local knowledge, and ethnoscience.

TEK is a system of knowledge, parallel and complementary to "Western scientific knowledge," which can be organized into three categories, each of which has its Western scientific equivalent:

- *The first category concerns knowledge about and a specialized vocabulary to describe specific components or aspects of plants, animals, and phenomena. This is somewhat similar to the field of systematics, with its attendant systems of classification.*
- *The second component concerns the development, evolution, and use of appropriate technologies for hunting, fishing, and trapping.*
- *The third category is more complex and is the least well understood, yet it is potentially the most significant of the three. It concerns the understanding of and intimate relationship with environmental systems as a whole. Aboriginal peoples often use such terms as the "web of life" to describe the connectedness of all elements of nature, including human beings. This holistic view is reflected in the language, culture, spirituality, mythology, customs, and social organization of local communities. The scientific discipline of ecology partially embraces this category, which may take the form of maps, documents, and oral history.*

The importance of TEK is reflected throughout land claim agreements and has been addressed by the Government of the Northwest Territories in its recent Response by the Government of the Northwest Territories to the Report of the Traditional Knowledge Working Group *(GNWT 1995b). A Traditional Knowledge Policy has been formulated, establishing the commitment of the Government of the Northwest Territories to incorporate traditional knowledge into its programs. TEK is a high priority among Inuit organizations, in various programs of the federal and territorial governments (e.g., under the AEPS), and in the Canadian Polar Commission. A major TEKMS study (Sallenave 1994) was recently completed as part of the Hudson Bay Programme, a project of the Canadian Arctic Resources Committee, the Environmental Committee of Sanikiluaq, and the Rawson Academy of Aquatic Science. The study, led by residents of Sanikiluaq, involved 28 communities, many of which are within the Nunavut and northern Quebec regions.*

Current issues and remaining concerns

The most serious global issue in the Arctic is the deposition of contaminants to the Arctic ecozones through long-range transport in the atmosphere. Many of the long-lived pesticides and organic chemicals used in North and South America, Europe, and Asia reach the Arctic quite rapidly.

Scientists cannot yet tell whether contaminant levels are harming Arctic ecosystems. Currently, a strategy is being developed to conduct further research on the fates and effects of atmospheric contaminants, but a much broader base of ecosystem-based information is required. The critical, and most complex, challenge is to find out at what concentration each contaminant begins to cause harmful effects (DIAND 1996a). Although concentrations of contaminants in the Arctic environment are generally lower than in source regions, the potential for impacts on human consumers of traditional country foods cannot be minimized. Solutions to this global problem are necessarily slow, but current deposition rates seem to be declining. Furthermore, international initiatives to further control these contaminants are still being implemented.

The transport of long-range atmospheric pollutants to the Arctic is a global issue that requires a global solution. Information

produced from the research initiatives of the AES Northern Contaminants Program has allowed Canada to take action internationally. These include the activities of the Arctic Monitoring and Assessment Programme, the Canada/Russia Program on Scientific and Technical Cooperation in the Arctic and the North, and work conducted under the United Nations Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution and the United Nations Commission on Sustainable Development (DIAND 1996a).

The most important regional issues are mining, tourism, and military activities. Mines are the only large-scale developments likely to be built in the Arctic ecozones in the near future. Tourism is one of the fastest-growing industries in these ecozones. Military activities have left a legacy of contamination, especially at various radar installations; although a great deal of cleanup has been done to date, there are still individual sites that need attention. The major concern at the radar sites is with PCBs, which are very long-lived in the environment.

The growth rate of the Inuit population is double the Canadian average. There are many young people facing difficult choices with respect to maintaining traditional Inuit lifestyles. The rapid rise in population increases the risk that wild game will be overexploited. The Arctic ecozones are not highly biologically productive. If the human population continues to grow, soon there will not be enough country food, at least in local areas.

Growth of northern communities will increasingly stress the environment, because the disposal of sewage and solid waste entails unique problems in areas of extreme cold and permafrost. Methods and technologies that have been developed in temperate climates must be replaced by innovations appropriate to the Arctic. Solid waste is even more of a problem there than it is farther south, because the high cost of transport precludes recycling. Innovative, local-scale solutions will be essential. There is no strategy to find solutions to common Arctic problems (e.g., sewage disposal).

To be sustainable, development must coexist with traditional Inuit values and culture. Progress has been made in the North with respect to providing a scientific understanding of the environment, integration of Indigenous knowledge with scientific knowledge, and the involvement of inhabitants in decision-making for effective resource management. Nevertheless, the existing knowledge base is weak, especially with respect to the impacts of external stresses, including harvesting. The greatest concern is the lack of a strategy to undertake multidisciplinary research to provide a broad-based understanding of Arctic ecosystems and their ability to sustain use and development.

Evidence of progress

International initiatives have been undertaken to make progress towards sustainable development. The following are examples of these initiatives:

- *Arctic Monitoring and Assessment Programme*: One of the environmental actions of the AEPS was to establish a comprehensive Arctic Monitoring and Assessment Programme. The mandate of this program is to monitor the levels of, and assess the effects of, anthropogenic pollutants in the Arctic environment. The monitoring program was completed in 1993, providing direction for monitoring activities for Arctic ecosystems and human health.
- *Canada/Russia Program on Scientific and Technical Cooperation in the Arctic and the North*: In October 1991, an agreement was reached between Canada and Russia for cooperation on contaminants in the Arctic. This resulted in an air monitoring station at Dunay Island in the Russian Arctic, which is a replicate of the three existing stations in the Canadian Arctic. This station has contributed to efforts to set up a circumpolar network for air monitoring. The agreement also enabled the exchange of environmental samples between Russia and Canadian laboratories for analytical intercalibration purposes.
- *United Nations Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution Preparatory Working Groups on Persistent Organic Pollutants and Heavy Metals*: In 1994, under the convention, a task force on POPs, led by Canada and Sweden, and a task force on heavy metals, led by the Czech Republic, recognized the need for a protocol to control long-range transport and deposition of POPs and heavy metals. In December of that year, the executive body to the Convention established new Preparatory Working Groups on POPs and Heavy Metals, with a mandate to assist the Working Group on Strategies with the preparation of POP and heavy metal protocols for submission to the executive body in November 1995. In the case of heavy metals, the mandate was also to further elaborate on the significance of natural sources with respect to the relative strengths of anthropogenic and natural sources.
- *United Nations Commission on Sustainable Development International Experts Meeting on Persistent Organic Pollutants*: At the spring 1994 session in New York of the United Nations Commission on Sustainable Development, Canada offered to cohost a meeting of world experts in the field of POPs to consider how all nations can work together to solve problems associated with the contaminants. The meeting, which was held in Vancouver on 4–8 June 1995, concluded that enough evidence exists on the adverse human health and environmental impacts of POPs to substantiate the need for immediate action. This action should be taken at regional, national, and international levels, and it should include bans and phaseouts for certain POPs. It was agreed that existing international laws and agreements do not provide for effective global POPs management and that domestic regulatory arrangements alone would not be adequate. It was also agreed that action would be effective only if it takes into account the significant social, economic, political, and cultural differences throughout the world. The need for development of effective, affordable, and accessible alternatives was emphasized, and a wide range of recommendations was made regarding, for example, donor and development agency policies, trade

and economic strategies, and bans on the use of POPs in agriculture (DIAND 1996a).

National initiatives under the AES have addressed contaminants, waste, water, and environment/economy integration. These programs have pioneered new ways of addressing sustainable development issues in the North and have greatly expanded the knowledge base, further demonstrating the potential benefits of integrating scientific and traditional knowledge. Although the full potential for cooperative resource management is yet to be realized, the stage has been set — by comanagement bodies with extensive powers established by the Inuvialuit Final Agreement and the Nunavut Land Claims Agreement, by regional land use planning exercises, and by the success of local initiatives to establish protected areas.

International cooperation and action on environmental issues, an expanded knowledge base, and a variety of new mechanisms for community-based decision-making are all critical if development in the Arctic ecozones is to proceed in a sustainable manner.

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THE STATE
of
CANADA'S
ENVIRONMENT

1996

PART III

NATIONAL OVERVIEWS

Introduction

Preamble

The chapters in Part II presented descriptions and analyses of the Canadian environment based on ecozone units that may be unfamiliar to some readers. Terms such as "Arctic," "boreal forest," "shield," "prairies," and so on are in common use, but people normally think of themselves as living in Sherbrooke or Nanaimo, in Quebec or British Columbia, not in a Mixedwood Plains or Pacific Maritime ecozone. Assembling quantitative information about each ecozone and their subdivisions has been particularly difficult, because environmental data usually have not been collected, organized, or published in terms of ecozones. That is likely to change in the future, and ecozone names and boundaries should become more familiar. Thinking in terms of ecozones recognizes the importance of natural divisions of the environment, rather than the political divisions (such as provincial, territorial, and national boundaries) that have traditionally been superimposed on the environment.

Yet political boundaries do have considerable significance for the environment, as they do for most facets of Canadian life. The fact that one can pass, by walking a few steps eastward, from Alberta into Saskatchewan, or by a few steps southward into the United States, does not mean a change in ecozone. But such steps may represent very substantial changes in the way that ecozone is viewed and managed.

Rationale for Overviews at the National Level

The state of the environment needs to be considered from a national viewpoint, as well as in ecozone terms. One reason is that this is how Canada's environmental record is considered and judged on the world scale. Although specific issues (such as logging practices or the decline of a fishery) can occasionally capture the headlines both here and abroad, Canada's environmental performance needs to be evaluated in terms of the overall task of protecting the environment and ensuring sustainable development for Canada as a whole.

There is also a strong national element in Canadian attitudes and lifestyles. It is the nationwide concern for the environment, sustained for several decades, that has placed the environment high on the agendas of federal, provincial, territorial, and local governments and has made it a constant theme for community groups and the news media. Similarly, it is the Canadian lifestyle that places Canadians, in respect of energy use and other measures, in sharp contrast to other countries with a comparable standard of living — excepting the United States.

To date, efforts to protect the environment have seldom been organized in terms of ecozones or similar units. Much environmental information, for example, is collected by individual provinces or territories, using their own systems, because these governments have primary responsibility for many environmental elements. Even when the environment has been studied, and some problems analyzed, in ecosystem terms, policies, actions, and expenditures tend to follow national, provincial, territorial, and other boundaries. This remains true even if the sponsors are voluntary organizations or the private sector. People are familiar with political units such as towns, counties, provinces, and nations, and it is natural to look for environmental information that is organized within such frameworks.

Lastly, and perhaps of most importance, the perspective needs to be extended beyond individual ecozones and their subdivisions, because ecozones are not self-contained units. Rivers flow from one ecozone into another; the winds that blow across a Canadian ecozone may bring with them pollutants that were injected into the atmosphere on the other side of the world. As well, human beings, wild birds, mammals, fish, and other biota cross ecozone boundaries constantly. A complete picture of the state of the Canadian environment must include those environmental features, problems, and solutions that exist in a broader dimension.

Major Themes

The following three chapters provide, respectively, overviews of important elements of the Canadian environment (Chapter 10), a survey of the impact that major sectors of the Canadian economy have on the environment (Chapter 11), and a review of the impact on the environment of urban growth, form, and activities (Chapter 12). These chapters also discuss action being taken to reduce environmental effects and make economic activities and cities more sustainable.

Several recurrent themes are evident throughout these three chapters. One of these is the important role of the exchange and transfer mechanisms that link the broad environmental elements. For convenience and clarity, it is usual to deal separately with each of the principal elements (air, land, water, and wildlife) and similarly with each of the main human activities (agriculture, forestry, fisheries, transportation, etc.). However, a change in one element or activity can have strong and pervasive effects throughout the environment, over wide areas, and over long periods. How forests are managed affects the wildlife they contain, soil erosion, and streamflow and, in the long term, may have important consequences for the Earth's carbon balance and global warming. Persistent pesticides released in one part of the world may travel in wind systems, then fall out of the atmosphere and eventually bioaccumulate in Canadian fish and other wildlife. Creation of dams on major rivers may affect flow patterns, erode river-

banks and riverbeds, alter the ice regime in winter, and have profound effects on the distribution and health of fish and other aquatic life. Low-density urban sprawl not only removes high-quality farmlands or wetlands from agricultural or wildlife use but also increases automobile use, energy consumption, and emissions. This has consequences for air quality, climate, and approaches to how resources are used or managed.

In these three chapters, as in other parts of the report, there is frequent mention of the lack of adequate data. Many readers may find this surprising. After all, the atmosphere, lakes, land, and cities of Canada have been studied for a long time, and impressive data sets have been collected for the whole country. The same is true of major sectors of human activity that affect the environment, such as agriculture, forestry, fishing, transportation, and energy use, and of a great many aspects of urban areas, such as population size and distribution, municipal water use, wastewater treatment, energy use, automobile ownership, and use of urban transit systems. Why, then, should it be so difficult to find reliable environmental information in these areas?

The simple answer is that most of the data that were collected in the past pertain to the issues of the time, and they do not provide all of the information needed to deal with current, emerging environmental issues. For example, there is a long record from hundreds of water-monitoring stations across Canada; in the past, however, these measurements were often limited to water quantity rather than water quality.

It is unfortunately the case throughout science that it is usually difficult to know what data are needed until the specific problem has been adequately defined. The environment is no exception, and problems identified in the last decade or so may require several decades of data collection before an overall and quantitative picture of the situation is available.

The data problem will never be completely solved. Consequently, the question arises: How much information is needed before action is taken? Some would argue that action needs to be taken as soon as there are signs of environmental damage; others insist on convincing proof when tracing an environmental effect back to a suspected cause, especially if taking action involves job losses and similar economic costs. A middle route — what is often termed the weight-of-evidence approach — is coming to be accepted as the best solution but is itself not easy to define. Essentially, it involves making the best possible assessments from the data and information available and, where there are suspected threats of serious or irreversible damage, applying the "precautionary principle" — i.e., not using lack of full scientific certainty as a reason for postponing preventive or remedial action.

Another recurrent theme is the need for cooperative action. To achieve an environmental objective important for an ecozone or a community, it may be necessary to achieve intergovernmental cooperation within Canada, across North America, or throughout the world. For example, cooperation between Quebec and the federal government, in the form of the St. Lawrence Action Plan, has brought major reductions in discharges of toxic and other polluting substances into the river during the plan's first five years (Government of Canada and Government of Quebec 1993). Air quality in Canadian cities cannot be further improved without continuing action by all three orders of government. Canada's acid rain problem needed cooperation from the United States before it could be tackled adequately. Protection of the stratospheric ozone layer has required worldwide agreement — in the form of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer — to end the use of major groups of ozone-depleting chemicals. Canada alone cannot rebuild the northwest Atlantic fisheries. There are many other issues for which coordinated action is an essential component of environmental improvement and sustainability in Canada. Cooperation is mentioned frequently in Chapters 10, 11, and 12.

SUSTAINABILITY AND INDICATORS OF SUSTAINABILITY

Part III, like the other parts of this report, is concerned with sustainability. People are no longer content with solving environmental problems that have been inherited from the past or that are created by present economies and lifestyles. Canadians want to know whether lifestyles in Canada are compatible with continued environmental quality and resource availability for future generations. If not, what changes does sustainability require? This brings a return, once again, to the questions of definition and measurement: How can sustainability be defined, how can it be measured, and what data are needed? Equally important, how can the long-term "health" of the ecosystem, measured in terms of its life support systems and biodiversity, be balanced against shorter-term priorities, such as employment and regional economic prosperity, that may sometimes conflict with those needs?

One major difficulty in answering such questions, and in choosing among different courses of action, is that there are many indicators of economic success or failure but, as yet, relatively few measures of sustainability. Because these economic indicators have been available for a considerable period, and because many of them have clear and often immediate implications on a daily basis, they have become part of the conventional wisdom that people use in organizing their lives and making decisions. Nowadays, for example, if the media report a change of several basis points in the Bank of Canada lending rate, families across the country realize that this has implications for their mortgage payments.

Some environmental indicators have also become part of daily life. Windchill or humidex values, pollen counts, ultraviolet radiation index values, and the presence of fecal coliforms at popular swimming areas are examples. Many environmental warnings, however, come in less understood terms, such as the

amount of persistent contaminants in Herring Gull eggs, or they involve complex relationships among environmental components. Consequently, most of the environmental signals that have been responded to thus far have been in the form not of trends or warnings, but of the unwanted effects themselves. That also used to be true of economic indicators. It was the stock market crash of 1929, and the years of depression that the crash precipitated, that led to the development of economic information, signals, and actions that are now taken for granted. With regard to environmental dangers, indicators are still too often established as a result of crises, such as the prairie dust storms of the 1930s, the eutrophication of Lake Erie in the 1960s, or the collapse of the Northern Cod fishery in the 1990s.

Work on development of sustainability indicators is ongoing internationally and within Canada. For example, the Organisation for Economic Co-operation and Development, the Worldwatch Institute, and the World Resources Institute are all developing indicators of environmental sustainability. Within Canada, a report on Canada's progress towards developing a national set of environmental indicators was produced by Environment Canada in 1991, and work is ongoing to develop these indicators.

If Canada is to achieve a sustainable future in environmental as well as in social and economic terms, early warning indicators are needed, along with measures of progress or decline, for the environment as well as for the economy. If possible, these need to be simple indicators, even if they are broad representations of much more complex situations. In other words, what are being sought are environmental indicators equivalent to the Bank of Canada rate or stock market indexes, and they clearly do not exist at present. They may, however, become available within a few years. Already there are indicators in important environmental fields that can be regarded as reliable guides. For instance, scientists agree that just two species — Lake Trout and a bottom-dwelling amphipod, *Diporeia hoyi*[1] — can serve as indicators of the physical, chemical, and biological health of Lake Superior's open waters (Government of Canada and Government of the United States of America 1987). If populations of these species are flourishing, Lake Superior remains in good shape. Similarly, although over 350 different chemicals have been identified in the waters of the Great Lakes, scientists have been able to justify a focus on only 11 "critical" pollutants: if these can be significantly reduced or eliminated, the actions taken will also affect the loadings of many other toxic chemicals.

The present report on the state of Canada's environment in the mid-1990s is one attempt to collect and interpret as many "vital signs" as possible. Environmental indicators are also a means of measuring progress towards sustainable development. At the national level, Environment Canada regularly publishes bulletins on indicators in the *National Environmental Indicator Series*. These bulletins serve as a significant source of information throughout the three chapters of Part III. Some of these bulletins provide short, succinct summaries of major environmental issues, such as urban air quality, energy consumption, and municipal water use and sewage treatment. Others focus on a representative feature that is a reliable guide to the sustainability of a larger ecosystem component. The state of Pacific Herring fish stocks, for example (see Box 11.9 in Chapter 11), is an indicator of marine resource sustainability on Canada's west coast.

Such environmental reporting will not avoid debate about the interpretation of data, any more than economic indicators eliminate disagreements on whether a rise or fall in interest rates is necessary for sustained economic growth. But indicators provide a common basis or currency for discussion and decision-making. Environmental indicators and environmental reporting should reduce the areas of uncertainty and enable the debate to focus on key issues of sustainability.

QUESTIONS TO BEAR IN MIND

As well as these recurrent themes — environmental interrelationships, data problems, intergovernmental cooperation, and indicators of sustainability — there are several questions that the reader may want to keep in mind in reading Part III.

1. At the broadest level, the World Conservation Strategy provides three requirements for environmental sustainability: maintenance of life support systems, preservation of biological diversity, and maintenance of the productive capacity of species and ecosystems. The reader might ask: How successful is Canada in meeting these requirements for sustainability, and where are the shortfalls?

2. As noted already, the environment has been a national priority in Canada since the late 1960s. It is reasonable to expect that many of the concerns that existed then should have been tackled effectively by now, and that, for many environmental issues, the stage of problem recognition and analysis should be well past. There should be evidence of effective action, and even of measurable improvement or progress towards sustainability. This is not true in every case. Some problems have been identified only recently; others may need many years of worldwide cooperation before improvement can be assured or even detected. Key questions here are: How long has this problem or need been recognized, and how successful has Canada been in responding to it?

3. In seeking answers to such questions, it is important to distinguish carefully between different stages and levels of action. Setting up a task force to study a problem is not the same as making a firm policy commitment to solving it. A policy commitment is not the same as

1. In the Canada–U.S.A. Great Lakes Water Quality Agreement of 1978, as amended by the Protocol signed on 18 November 1987, Supplement to Annex 1, paragraph 3, this organism is named *Pontoporeia hoyi*. It is now recognized that the species was misidentified, although the Great Lakes Water Quality Agreement has not yet been amended to recognize this.

effective action to implement the policy. All these stages may be necessary or appropriate at different times. The issues become: How much progress has been made towards a sustainable solution, and is a particular solution being applied throughout Canada or just in a few locations or sectors?

4. Another vital question is the extent to which environmental problem-solving and improving environmental sustainability can be achieved by collective action (e.g., legislation, regulation, taxes, etc.), and how much has to depend on changes in individual lifestyles. Most Canadians want a high-quality and sustainable environment; most also want a rich quality of life and sustained economic prosperity. If, as the evidence suggests, some choices need to be made, what is this likely to mean for the environment?

5. Finally, the reader of Part III should be alert for what might be described as myths and inadequate explanations. Some of these may be matters that have been taken for granted in the past but that need reconsideration in the light of the evidence in Part III. For example, Canada's massive per capita energy consumption is often justified in terms of the vast size of the country and the cold winter climate. But the Canadian climate is not so different from that of Sweden, which uses far less energy per capita, and one in three Canadians lives in one of the three largest cities. Size and climate clearly have *something* to do with energy use, but how much? What other assumptions or explanations for environmental performance need to be examined more carefully?

There are no simple answers to most of these questions. However, by keeping them in mind while reading the national overviews that follow, the reader can become a better-informed participant in the ongoing process of evaluation and decision-making leading towards sustainable development.

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Acknowledgements

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Chapter 10 Environmental Conditions and Trends

Highlights

Atmosphere

Numerous human activities, such as the combustion of fossil fuels for heat, transportation, and other energy requirements, metal processing, pulp and paper processing, and agricultural practices such as pesticide and fertilizer applications, introduce gaseous and particulate contaminants into the air. Other activities, such as the disturbance of natural land cover through agriculture, forestry, and construction, reduce the capacity of ecological processes to cleanse the atmosphere. Atmospheric contaminants of human origin range from common substances, such as oxides of carbon, nitrogen, and sulphur, to more exotic, often synthetic substances, such as chlorofluorocarbons (CFCs). As a highly mobile component of the ecosphere, the atmosphere can transport these contaminants long distances from their place of origin. Hence, no part of Canada is free from atmospheric contamination of one type or another.

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In recent years, considerable progress has been made in Canada in reducing the emissions of certain contaminants. For example, atmospheric concentrations of lead, a substance known to have numerous adverse effects on human health, have fallen dramatically since the early 1970s. This has largely been due to the phasing out of lead in gasoline. Sulphur dioxide emissions, a major contributor to acidic deposition, were cut almost in half in Canada between 1980 and 1994. Further, Canada has been a leader in the elimination or phasing out of substances known to deplete stratospheric ozone, such as CFCs.

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Success has been harder to come by in other cases. Ground-level ozone, a secondary pollutant and key component of photochemical smog, has not diminished to any extent in those regions of Canada where it is of most concern: the lower Fraser Valley of British Columbia, the Windsor–Quebec City corridor, and southern New Brunswick–southwestern Nova Scotia. This is because Canadian and U.S. emissions of substances that lead to the formation of ground-level ozone — volatile organic compounds and nitrogen oxides — remain close to the levels of the mid-1980s. If all other climatological variables were left unchanged, this situation could be aggravated should annual average air temperatures continue to rise, possibly as a result of climate change.

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Land

At 9 970 610 km^2, Canada's surface area (land plus fresh water) is the second largest in the world and represents 7% of the global land mass. Coniferous forest covers the largest area, almost 28%. With 29.7 million people in 1995 — an average of only about 3.0 people per square kilometre — Canada is home to just 0.5% of the world's population. However, Canada's population is not distributed evenly throughout the country — about 80% of Canadians live in urban areas covering only 0.2% of the country's total land area.

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More than any other industrialized nation, Canada depends on the land for its economic well-being. One in three workers is employed directly or indirectly in agriculture, forestry, mining, energy, or other land-based activities. Each year, these same activities account for approximately half of the value of exports. Beyond its significance to the economy, Canada's land — its quality and diversity — is closely linked to our sense of national identity.

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With the goal of achieving sustainable land use, Canada has identified a number of land-related priorities. Among these is the strengthening of intergovernmental relations through various ministerial harmonization councils that aim to eliminate overlap and duplication with respect to natural resource issues. Increasing emphasis is also being placed on multistakeholder partnerships and on the development and application of an ecosystem approach to land planning and management.

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Fresh Water

Lakes and rivers cover 7.6% of Canada's surface, and 9% of all fresh water discharged into the world's oceans is from Canada. Despite this relative abundance, the Canadian prairies and some of the valleys in the interior of British Columbia have a limited supply of water and suffer from periodic shortages. This situation could get worse if current projections of climate change are accurate.

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The impacts of atmospheric changes on freshwater ecosystems are becoming better understood: for example, some drainage basins and lakes in eastern Canada recover quickly after acidic deposition is reduced, whereas others may need years to regain their balance; long-range transport of contaminants throughout the northern hemisphere may lead to the deposition of these substances in the Canadian Arctic; and higher levels of ultraviolet-B radiation are putting aquatic food webs at risk.

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Compared with most other countries, Canada enjoys relatively high-quality water. Nevertheless, problems remain. Among them is contamination of groundwater, which more than six million Canadians rely on for their water supplies. Groundwater contamination often results from earlier inadequate management of wastes or industrial chemicals. Because groundwater moves so slowly, it may be decades before a problem is detected — possibly long after the source of the contamination has disappeared. Well water, though, is most often contaminated by fecal coliform bacteria and nitrates. Recent surveys suggest that 20–40% of all rural wells may be affected.

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Many of the impacts of human settlements and industries on freshwater ecosystems occur primarily within the boundaries of the same drainage basin or catchment area. For this reason, freshwater ecosystems are often best managed by the management of their drainage basin. This approach is currently being exemplified at sites throughout Canada.

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Oceans

With the longest coastline in the world, Canada has a wealth of coastal and marine resources, which have contributed substantially to the nation's economic growth. Yet the significance of oceans to Canada and other countries extends beyond the economic value of the resources contained in territorial waters. More importantly, oceans play a key role in the global ecological processes that influence all life and living conditions on this planet.

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Marine ecosystems are under a variety of pressures from human activities. Persistent plastic debris can snare or choke birds, fish, and other marine animals. Oil spills, effluent discharges, dumping, and runoff can degrade marine habitats, harm marine biota, and affect fisheries and other uses of marine renewable resources. Climate change could lead to rising sea surface temperatures and redistribution of marine biota. It has been estimated that continued greenhouse warming could cause the world's sea level to rise at a rate of 1–11 cm per decade over the next century, increasing coastal erosion and flooding in low-lying areas.

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Managing marine environmental quality and resources cannot be done in isolation or without the cooperative efforts of all orders of government, nongovernmental groups, and the private sector. Various regional action plans are in place to examine special problems in marine and freshwater ecosystems. The federal government is committed to establishing three additional national marine conservation areas by 1996. Sustainable coastal zone management aims to foster well-designed economic development integrated with environmental protection and conservation.

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Wildlife

Canada's wildlife population encompasses more than an estimated 138 000 species. Of these, the number known to exist includes about 4 000 vascular plants, nearly 1 800 vertebrate animals, and more than 44 000 invertebrates.

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Wildlife continues to be under pressure throughout the country from a wide array of human activities as well as natural phenomena. Agriculture, forestry, fishing, and urban and industrial development, for example, continue to exert direct pressures on wildlife and to effect changes in the quality and quantity of wildlife habitat over large areas. The results are seen in the growing number of species that are recognized to be at risk of eventual extinction. As of 1995, 243 species, subspecies, or populations were considered endangered, threatened, or vulnerable, another 11 were considered extirpated, and 9 were extinct. Pressures on native wildlife are also reflected in the presence of toxic contaminants in tissues of living organisms and in the ongoing invasions of nonnative species into Canadian ecosystems. Many introduced species that invaded years ago, such as the Purple Loosestrife and Zebra Mussel, continue to expand into new areas, providing strong competition for or even overpowering native species. Climate change could have an impact on native wildlife, largely through potential changes to existing habitats.

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Encouraging signs include progress in the development of new legislation and formulation of plans to protect endangered, threatened, and vulnerable species and restore their habitats. Populations of all North American ducks and most species of geese have been on the rise in recent years. Although toxic contaminants persist in tissues of living organisms, levels of most have decreased significantly since the 1970s and 1980s. As well, regulations are in place or voluntary initiatives have been taken to control emissions of the majority of the most significant toxic substances. Further, Canada continues to add to its networks of national, provincial, and territorial parks, national wildlife areas, migratory bird sanctuaries, lands protected through landowner stewardship programs, and other protected areas.

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Canadians are accustomed to hearing their country described simply in terms of its size. Canada has the longest coastline in the world, facing three oceans, and the second largest continental shelf. Canada's land area is second only to that of the Russian Federation. It extends from east to west across six time zones and from north to south across 40 degrees of latitude, from the north coast of Ellesmere Island to Pelee Island in Lake Erie. There are two million lakes and 100 000 glaciers in Canada. These are just a few of the statistics that underscore Canada's size.

One consequence of the country's vastness has been the assumption in the past that the major components of Canada's environment were virtually inexhaustible in proportion to the needs of Canada's population. There appeared to be land, water, air, forests, energy, minerals, and other resources aplenty. That perception has changed substantially in recent decades. It has become all too evident that the air in and around cities can easily become polluted, that lakes and rivers can retain certain toxic chemicals for long periods, that soil can be eroded swiftly, that fish stocks can be exhausted, and that species of plants and animals can become endangered or extinct.

What has been slower to gain wide acceptance is how closely the main elements of the environment — air, land, water, and living things — interact with one another as ecosystems, on every scale from the local to the global. This delay in understanding has been typical of environmental scientists as well as the general public. Scientific training traditionally has produced specialists in a particular discipline: meteorologists, geologists, hydrologists, botanists, zoologists, and so on. Many of these scientists became even more specialized as they acquired more expertise in their field or as they concentrated on a particular region of Canada.

It is natural to classify and subdivide the world so that it may be understood and dealt with in a reasonably organized manner. Specialization within a discipline facilitates understanding of the huge amount of knowledge that is available. Such classifications are useful divisions in what is, however, essentially a continuum. Although the following sections are arranged in the familiar pattern of air, land, water, and living things, it is recognized that even these broad divisions are far from absolute: the environment always involves continuous exchanges among its elements.

The magnitude and impact of these exchanges have been demonstrated in many ways in recent decades. Releases of chlorofluorocarbons (CFCs) and halons at the Earth's surface led to depletion of ozone in the stratosphere. With the thinning of the stratospheric ozone, more ultraviolet (UV) radiation from the sun reaches the Earth's surface, affecting the survival of many species and increasing skin cancers in humans. Mercury — whether released from anthropogenic sources (e.g., fossil fuel combustion or, formerly, pulp and paper plant releases) or from natural sources (e.g., weathering, crustal degassing, or volcanoes) — becomes converted into a form that enables it to enter food webs and become a health threat to organisms, including humans, at the top of such webs; on the other hand, some recent research is now indicating that increased levels of ultraviolet radiation actually result in mercury being converted back to less toxic forms that are not a threat to humans. Exchanges between the atmosphere and ocean in the tropical Pacific periodically give rise to major weather disturbances throughout the world: these "El Niño" events may subsequently shape the seasonal climate of much of North America and have global costs counted in billions of dollars. Excessive use of fertilizers, even "organic" ones, can cause high levels of nitrates in groundwater used by rural communities, sometimes exceeding the maximum acceptable concentrations specified for drinking water, again with dangerous implications for human health. Global sea level has risen by between 10 and 25 cm over the past 100 years, and much of the rise may be related to the increase in global temperature.

Viewed from an ecosystem perspective, the atmosphere is an important medium for the exchange of matter within and among ecosystems. These exchanges make it possible for life to continue indefinitely, even though the resources that support it are finite. For instance, the atmosphere is a major medium in the natural cycles that transfer biologically essential substances, such as water, carbon, and nitrogen, from one component of the environment to another. These transfers involve complex exchanges of massive amounts of water between nonliving components of the environment, such as air, soils, bodies of fresh water, and oceans, and living plants, animals, and microorganisms. The atmosphere's other contribution to the exchange of matter is through its ability to transport materials from one place to another. Winds pick up water, gases, pollen, and other particles from the Earth's surface, moving them sometimes only a short distance, sometimes thousands of kilometres.

The atmosphere is also important as a medium for the exchange of energy. Atmospheric circulation redistributes heat from regions that receive more solar energy to regions that receive less. At the same time, the atmosphere's greenhouse gases, such as water vapour, carbon dioxide (CO_2), and methane (CH_4), retard heat loss into space and keep the planet warm enough to support life. The climate produced by the atmosphere's interactions with land, bodies of fresh water, and oceans is a dominant factor in shaping ecosystems and human activities.

Although land is less of a transporting agent than either air or water, it too is a dynamic feature in which the processes of change closely rely on other elements of the ecosystem. For example, the nature of the soil itself depends on such factors as the type of underlying bedrock and the rate of rock weathering, upward and downward movement of moisture and minerals, and plant cover and humus. These, in turn, depend on climate. Drainage determines the water content of soils and consequently much of its chemical activity.

The physical and chemical processes of soil formation require thousands of years to create well-developed soils. Because most of Canada has been, in geological terms, recently glaciated, and because much of the land is frozen for all or a large part of the year, most soils have not had sufficient time to develop fully and so remain thin or skeletal. Under natural conditions, soil development in the southern portion of Canada takes place at an average rate of less than 5 mm per century. In contrast, soil erosion, by wind or running water, can take place rapidly, with results sometimes evident in a single day.

Surface water is a vital element in the Canadian environment, sustaining crops, forests, and wildlife habitats, providing an important energy source, meeting residential, industrial, and other demands, and acting as a means of transport, both for commodities and for wastes. Canada's rivers discharge about 9% of the world's renewable water supply, proportionate to the country's total area, which makes up about 7% of the world's land mass. These rivers discharge into the Pacific Ocean, Arctic Ocean, Hudson Bay, and Atlantic Ocean basins, with a minor flow to the Gulf of Mexico. Over half of the surface runoff flows towards the north, away from the industrial, agricultural, and population centres along Canada's southern border. Of significance to most Canadians, however, is the presence in the populated zone of the Great Lakes and the St. Lawrence and Fraser rivers and also of the Saskatchewan–Nelson river system across a wide area of the Prairie provinces.

Although not readily visible at the surface, groundwater is also an important component of the hydrologic cycle. In volume, it is much larger — perhaps a hundred or more times — than the amount of surface water found in lakes and rivers (Environment Canada 1993a). Groundwater moves slowly through underground aquifers. Some of it reaches the surface, where it may contribute up to three-quarters of streamflow, particularly in regions where bedrock is permeable, such as in Prince Edward Island. In times of drought, when there is little or no runoff from the land, streamflow may consist entirely of groundwater discharge. Contamination of groundwater can therefore be a major factor in the pollution of lakes and rivers. In every province except British Columbia, groundwater provides 90% or more of total water supplies in rural areas; as many people depend on untreated water from individual wells, its quality is a matter of vital concern throughout rural Canada (Statistics Canada 1994a).

The Atlantic, Pacific, and Arctic oceans, which form Canada's boundaries on three sides, facilitate transport, provide food, modify local climates, and support a multitude of leisure activities. From an environmental standpoint, the oceans are also receiving waters for solid and dissolved materials eroded from the land, for industrial and municipal wastes, and for materials transported via the atmosphere.

Marine ecosystems are normally divided for environmental purposes into the deep sea, the continental shelf (which extends to a depth of roughly 150 m and is narrow on Canada's Pacific coast but very extensive on the Atlantic side), and the coastal and estuarine areas. It is in these last regions, including the Gulf of St. Lawrence, Bay of Fundy, Strait of Georgia, and Canada's Arctic Archipelago, that small physical or chemical changes can have major environmental effects. The cause of these changes may be pollution — from municipal effluents, pesticide and fertilizer runoff, or coastal industrial sites — or sediments resulting from erosion due to shoreline developments. No matter what the cause, the environmental effects may be spread over wide areas through ocean currents.

The recognition that Canada's environment must be viewed as an integrated system of ecosystems has implications for all the main environmental elements — air, land, water, and living organisms — but especially for wildlife, a term that includes all nondomesticated species of plants, vertebrate and invertebrate animals, and microorganisms. People are accustomed to thinking of wildlife in terms of individual species: vertebrate animals such as Grizzly Bear, Peregrine Falcon, Leopard Frog, or Pacific Herring; invertebrate animals such as Monarch Butterfly, Spiny Waterflea, or Blue Mussel; or plants such as Douglas-fir, Purple Loosestrife, or Eelgrass. Today, we need to think more in terms of the wide variety of ecosystems that provide the remarkable range of habitats for all kinds of wildlife.

In addition, the health of wildlife, especially those species at or near the top of food webs, is increasingly seen as providing an indicator that is directly relevant for human health and well-being. For example, data suggest that exposure to similar mixtures of toxic substances will produce neurobehavioural and developmental effects in both wildlife and humans (Government of Canada 1991a).

Using wildlife as a measure of the well-being of Canada's ecosystems is a complex exercise: individuals, populations, communities, and ecosystems must all be considered. But such an integrated approach frequently comes up against a problem: because an ecosystem approach is relatively novel, data and research on interactions among species and throughout an ecosystem are often unavailable. The information and research gap is being filled, but the work cannot be done overnight.

Particularly lacking is information about the less familiar groups, such as invertebrate animals and nonvascular plants, and about the interactions among organisms that are essential to ensure healthy ecosystems. Such information is vital. Bacteria, algae, fungi, trees, and invertebrate animals play powerful roles in essential ecological processes, such as oxygen generation, nitrogen fixation, nutrient cycling, waste decomposition, water purification, soil formation, and climate control. The health and abundance of mammals, including humans, and of birds, fish, and other vertebrate species cannot be separated from the well-being of the invertebrates, plants, and microorganisms upon which they ultimately depend.

Atmosphere

The human impact

For more than three billion years, Earth's atmosphere has been shaped and modified by interactions with living things. Until the coming of the industrial revolution, however, human beings did not have much of an effect on these processes. Since then, human activities have resulted in increasingly significant changes to the composition of the atmosphere. These impacts have been made in two ways: first, through emissions of polluting gases and particles to the atmosphere; and second, through physical alterations to the landscape.

Pollutant emissions of anthropogenic origin are the consequence of a broad range of activities, and their immediate effect is to diminish the quality of the surrounding air, both aesthetically and chemically. Some pollutants reduce visibility or give off strong odours. Some react with various building materials, leading to the decay of monuments and other structures. Others can impair the health of animals (including humans) and plants.

Physical and chemical atmospheric processes soon disperse or destroy many of these substances. Others, however, are more persistent in the atmosphere and can have broad regional and even global effects. These substances can be carried long distances by atmospheric currents and affect places remote from significant sources of emissions. Some substances also alter ecologically important functions of the atmosphere itself, such as the regulation of temperature by greenhouse gases or the absorption of harmful solar ultraviolet radiation by ozone in the stratosphere.

Landscapes also affect the atmosphere. Land surfaces have a considerable influence on climate processes, absorbing and reflecting solar radiation and affecting the flow of air across the Earth's surface. Exposed soils from deserts and tilled fields provide a source of particulate matter to the air, and vegetation produces carbon dioxide through respiration, removes it through photosynthesis, and releases moisture through transpiration. In a balanced system, all removal of carbon dioxide by photosynthesis is offset by emissions through respiration and decay.

When the character of the landscape is changed, its effect on the atmosphere changes also. A tilled field, for instance, reflects more sunlight, releases more particulate matter to the air, and transpires less moisture than the forest that once stood in its place. The most easily observed example of such changes is the urban "heat island" effect — cities are typically warmer than the surrounding countryside, particularly during clear, calm nights (see Chapter 12). On a larger scale, massive deforestation in many parts of the world contributes to the buildup of carbon dioxide in the atmosphere, enhancing the greenhouse effect.

These interactions give rise to four air quality problems. The first is the effect of pollutants on local air quality, especially in and near urban centres. This is primarily a human health concern, but it is not without implications for farm crops and natural ecosystems. The second is the acidification of rural and remote areas, particularly in eastern Canada, as a result of the long-range transport of atmospheric pollutants. The third involves destruction of the protective ozone in the Earth's stratosphere, and the fourth concerns the possibility of long-term climate change as a result of rising concentrations of greenhouse gases in the atmosphere.

Local air quality

Local air quality in Canada is customarily defined in terms of five common pollutants — sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), suspended particles, and ground-level ozone (O_3). These are frequent constituents of urban pollution; as such, they have the potential to affect the majority of Canadians. They are formed, directly or indirectly, as by-products of industrial activities and the burning of fossil fuels. With the exception of carbon monoxide, which impedes the absorption of oxygen into the bloodstream, these substances irritate the eyes and respiratory system. They reduce the efficiency of the lungs and aggravate existing respiratory conditions, and they can induce coughing and pain on deep breathing; they are particularly harmful to children, to people with chronic respiratory disorders such as asthma and bronchitis, and to those with cardiopulmonary disease. Sulphur dioxide, nitrogen dioxide, and ozone are also harmful to trees and other plants and can damage rubber, plastic, and other materials by reacting with and weakening them.

National Ambient Air Quality Objectives (NAAQOs) have been established in Canada for each of the five common pollutants. These objectives are target levels, defined to provide protection for humans, other life-forms, and/or inanimate objects such as soil and water. The system is three-tiered, providing limits for "desirable," "acceptable," and "tolerable" ranges of air quality (Table 10.1). The maximum tolerable level represents a pollutant concentration beyond which immediate action needs to be taken to protect the health of the general population.

Average levels of common pollutants measured in urban areas across Canada since 1979 are illustrated in Figure 10.1. Between 1979 and 1993, concentrations of carbon monoxide, sulphur dioxide, suspended particles, and nitrogen dioxide fell by 56%, 46%, 38%, and 28%, respectively. The frequency of occurrence of *high* levels of these pollutants has also diminished considerably (see Chapter 12, Fig. 12.9). However, concentrations of ozone still rise periodically to unacceptably high levels in many localities. The presence of a variety of toxic pollutants in urban air is also of concern. These have been linked not only to respiratory diseases but also to a wide range of other health problems.

Ozone

Ozone gas occurs naturally in varying amounts in the Earth's atmosphere up to a height of at least 100 km. In the *stratosphere* (some 10–50 km above the Earth's surface), ozone is produced by the action of high-energy solar radiation on oxygen. Stratospheric ozone provides the critically important function of shielding humans and other organisms from biologically harmful ultraviolet radiation emitted by

the sun (see Chapter 15). Natural phenomena, such as lightning, also form ozone at *ground level*, but in very small amounts. However, human activity can lead to high enough concentrations of ground-level ozone that it becomes a harmful pollutant. Although not directly emitted in significant quantities, ground-level ozone forms as a secondary pollutant when other substances, known as its precursors, react in the presence of sunlight. The main precursors for human-induced ozone formation are nitrogen oxides (NOx) and volatile organic compounds (VOCs), both of which result primarily from the combustion of fossil fuels in motor vehicles. VOCs are also present in the vapours emitted by products such as gasoline, paints, and solvents. There are also natural, or biogenic, sources of nitrogen oxides (e.g., the soil) and VOCs (e.g., certain species of trees and shrubs).

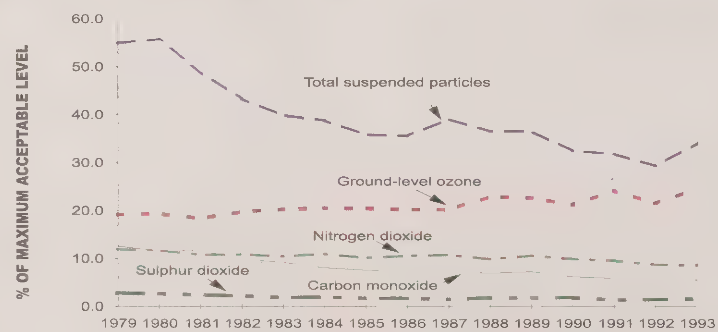
Table 10.1
National Ambient Air Quality Objectives (NAAQOs)

Pollutant	Averaging time	Maximum desirable concentration[a]	Maximum acceptable concentration[a]	Maximum tolerable concentration[a]
Sulphur dioxide	Annual	11 ppb	23 ppb	–
	24 h	57 ppb	115 ppb	306 ppb
	1 h	172 ppb	344 pbb	–
Suspended particulates	Annual	60 μg/m³	70 μg/m³	–
	24 h	–	120 μg/m³	400 μg/m³
Ozone	Annual	–	15 ppb	–
	1 h	50 ppb	82 ppb	153 ppb
Carbon monoxide	8 h	5 ppm	13 ppm	17 ppm
	1 h	13 ppm	31 ppm	–
Nitrogen dioxide	Annual	32 ppb	53 ppb	–
	24 h	–	106 ppb	160 ppb
	1 h	–	213 ppb	532 ppb

[a] Conditions of 25°C and 101.32 kPa are used as the basis for conversion from μg/m³ to ppm (parts per million) or ppb (parts per billion).

Source: Furmanczyk (1994).

Figure 10.1
Trends in common air contaminants, 1979–1993



Note: Maximum acceptable levels are 82 parts per billion (ppb) for ozone (1 h), 344 ppb for sulphur dioxide (1 h), 213 ppb for nitrogen dioxide (1 h), 13 parts per million (ppm) for carbon monoxide (8 h), and 120 μg/m³ for total suspended particles (24 h). Data plotted are average annual levels at all monitoring stations.

Source: Environmental Technology Centre, Environment Canada.

Together, ground-level ozone and a number of other pollutants make up what is known as photochemical smog. Other components of photochemical smog — such as peroxyacetylnitrate (PAN) — are also hazardous to human health and vegetation, but ozone is by far the most abundant.

Because ozone formation depends on strong sunlight and is accelerated by heat, ozone concentrations tend to peak during the day. For these same reasons, photochemical smog is primarily a summer phenomenon. In summer, warm weather and temperature inversions (a temperature inversion exists when the air temperature increases with elevation) allow increased production of ozone and an accumulation of its precursors in the lower levels of the atmosphere. These periods of high concentrations are sometimes of local origin (in cities or downwind of large cities) and sometimes originate from sources at great distances upwind.

Cities, with their heavy traffic and, to a lesser extent, their concentrated industrial facilities, are prone to high ozone levels. However, the situation is complicated by the fact that some urban air contaminants actually react with and "scavenge" ground-level ozone, reducing local levels. Advancing air masses can carry ground-level ozone and its precursors hundreds of kilometres from their point of origin to rural sites where levels of such "scavenging" contaminants are much lower. Thus, ozone concentrations in rural areas can be higher than in the cities themselves. Because crops such as wheat, corn, soybeans, tobacco, tomatoes, and beans are sensitive to ozone, the economic consequences of rural ozone pollution during the growing season can be considerable. Ornamental plants are affected as well: one study has estimated that growers of ornamental plants in southern Ontario lose between $17 million and $70 million a year as a result of ozone damage (Pearson and Donnan 1989); another study esti-

mates losses in British Columbia of up to \$9 million (Rafiq 1986).

Under Canada's NAAQOs, the maximum acceptable ozone concentration for a one-hour period is 82 parts per billion (ppb) by volume; the U.S. counterpart is 120 ppb. The Canadian threshold was established based on effects on vegetation, but more recent information indicates that human health effects can occur at ozone levels below 82 ppb (Table 10.2). During a very warm summer, most major Canadian cities will have at least one day, and some will have several days, when ozone concentrations climb above 82 ppb. In the Windsor–Toronto area, maximum concentrations during the worst of these events typically fall between 110 and 160 ppb (CCME 1990).

Not surprisingly, it is the Windsor–Quebec City corridor, the most urbanized and industrialized part of Canada, and a region with relatively warm summers, that experiences the highest average number of days with unacceptable ozone levels (Fig. 10.2). A significant proportion of this pollution originates in nearby U.S. cities such as Detroit and Cleveland. In fact, U.S. sources are estimated to account for 50–60% of the ozone measured in southwestern Ontario during cloud-free days (Yap et al. 1988). Because of this transboundary contribution, and because local nitrogen oxide emissions in cities can actually reduce ozone levels by scavenging the ozone from the air, elevated ozone levels can occur more frequently at rural sites in southwestern Ontario than in urban industrial centres such as Toronto and Hamilton. Between 1985 and 1992, for example, Long Point on Lake Erie experienced more than seven times as many ozone pollution events as downtown Toronto (OMEE 1993).

Southern New Brunswick and southwestern Nova Scotia also experience ozone problems, even though there are no large sources of ozone precursors in the area itself. Most of this pollution originates in Boston and other sites in New England and travels across the ocean without being destroyed or deposited to the water (CCME 1990).

Ozone pollution is also a problem in British Columbia's lower Fraser Valley, where the surrounding mountains create a pocket of stagnant air in which pollutants from the Vancouver and Seattle areas accumulate. The highest ozone concentrations, with levels peaking at about 150 ppb, occur at the eastern end of Burrard Inlet near Port Moody (CCME 1990).

In 1990, 1992, and 1993, both the frequency and the severity of ozone pollution were noticeably lower than in the late 1980s, largely because weather conditions were less conducive to ozone formation. However, U.S. and Canadian emissions of nitrogen oxides and VOCs have remained almost constant for a decade or more. Canadian nitrogen oxide emissions have been estimated at a relatively steady 2.0 million tonnes per year since 1980, about 10% of U.S. emissions. Canadian VOC emissions, meanwhile, have been approximately 2.0–2.5 million tonnes per year since 1985 (Pollution Data Analysis Division, Environmental Protection Service, Environment Canada), again about 10% of U.S. levels (U.S. Environmental Protection Agency 1994). The potential for ozone pollution therefore remains as high now as it was a decade ago. Global warming could, over time, exacerbate the situation.

Table 10.2

Summary of the health effects of ground-level ozone

Population	Health effects at following ozone concentrations (ppb, 1-h maximum)[a,b]			
	<50 (good)	50–80 (fair)	80–150 (poor)	>150 (very poor)
General population (adults and children)	No known harmful effects	Respiratory symptoms with heavy outdoor exercise in sensitive people	Inflammation of respiratory tract Decrements in pulmonary function Airway hyperreactivity Larger proportion of population experiences symptoms with heavy outdoor exercise Reduced capacity for exercise/physical work	Higher probability of effects described in "poor" category Respiratory illness in children with less intense exercise
Individuals with heart or lung disease (including asthma)	No known harmful effects	Above, plus possible increased medication use, physician/emergency room visits, and hospital admissions	Above, plus higher probability of effects described in "fair" category Possible mortality	Higher probability of effects described in "poor" category

[a] 50 ppb = maximum desirable concentration; 82 ppb = maximum acceptable concentration; 150 ppb = maximum tolerable concentration. Air quality descriptors are given in parentheses.

[b] Probability and severity of expected health effects increase with increasing exposure (time and level).

Source: Adapted from Pengelly et al. (1993).

To deal with this problem, a national Management Plan for Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOCs) was released in 1990. The plan proposes to reduce nitrogen oxide and VOC emissions through a broad array of strategies, including improvements in energy efficiency, product reformulations, changes to combustion and production processes, improvements to emission control devices, and prevention of vapour leakage from fuel storage tanks.

These actions are expected to reduce nitrogen oxide and VOC emissions nationally by 10% and 15%, respectively (compared with 1985 levels) by 2005. Similar initiatives are also under way in the United States. When fully implemented, the two programs should reduce maximum ground-level ozone concentrations in Canada by 15–35% (CCME 1990), unless a trend towards warmer summers offsets these gains.

Suspended particles

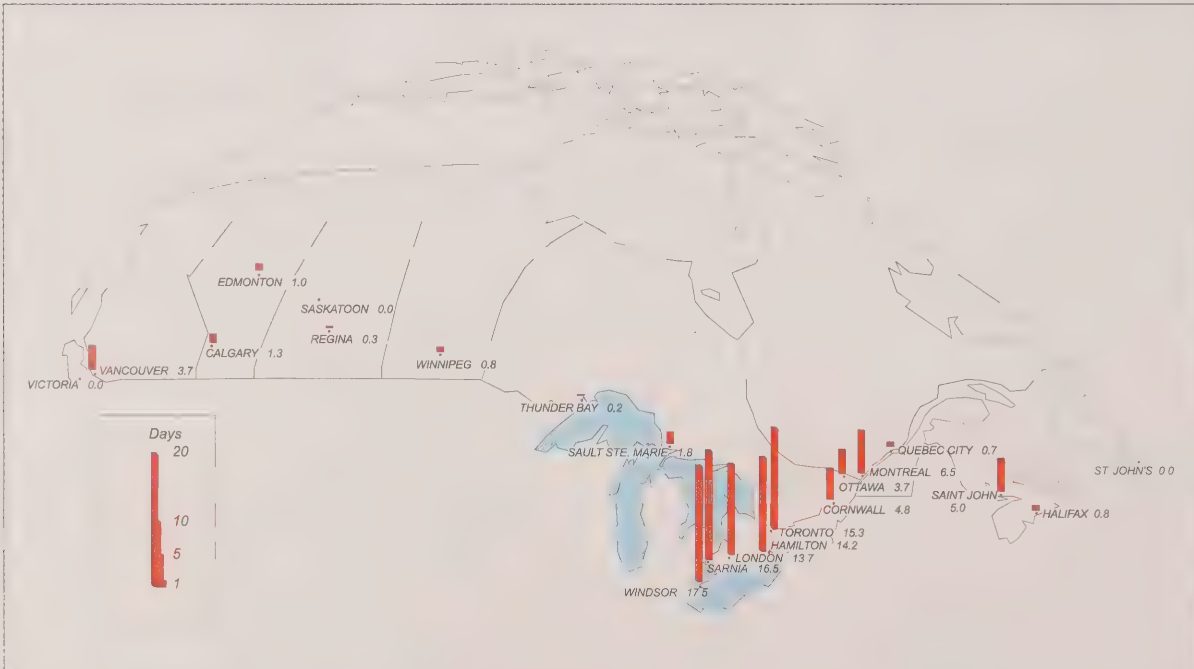
Unlike ozone, particulate matter may be found in high concentrations in the air at any time of year. Much of it comes from natural sources such as windblown dust, pollen, soot from forest fires, and sea salt. However, human activities such as transportation, agriculture, mining, smelting, metal processing, construction, and pulp and paper processing can add considerably to natural concentrations.

Anthropogenic airborne particulates that are less than 10 µm in diameter (a micrometre is one-thousandth of a millimetre) are primarily a consequence of industrial processes and motor vehicle use. These are the particles of greatest concern because of the hazard they pose to human health. They are easily inhaled and can irritate the respiratory tract, thereby aggravating existing conditions such as asthma and cardiopulmonary disease. In 1994, the World Health Organization ceased recommending a threshold level for airborne particles because no specific concentration represented an apparent threshold (WHO 1994). Rather, recent data suggest a continuum of effects, rising with exposure. Increased concentrations of particles in the air are associated with higher risk of mortality as a result of respiratory and cardiac disease and lung cancer. Health effects associated with a rise in particle concentrations include increases in hospitalizations and visits to emergency wards for respiratory problems, increases in the number of days of restricted activities among adults and school absenteeism among children, increases in the number of symptoms of respiratory disease, and minor reduction of respiratory functions (Vedal 1995).

In a survey of Ontario sites in 1992, inhalable particles constituted 38–61% of total suspended particulates (OMEE 1993). Particles in this size range also

Figure 10.2

Average number of days when the one-hour maximum acceptable ozone concentration (82 ppb) was exceeded (1987–1992) in selected cities



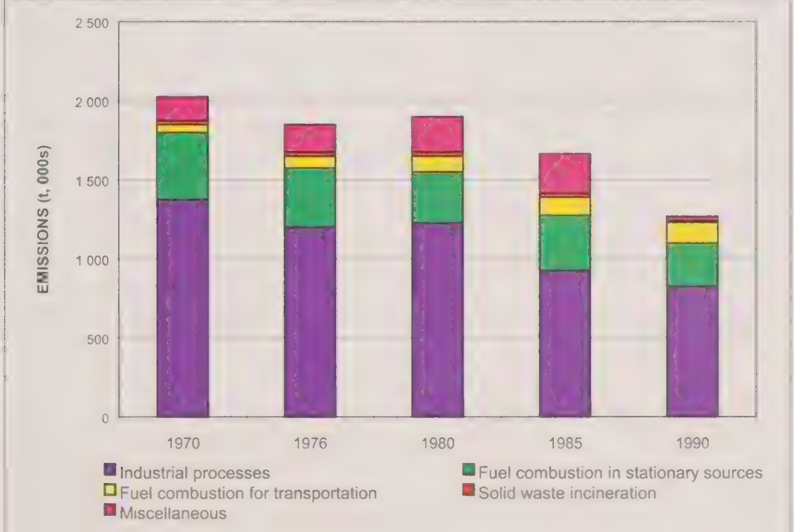
Source: T. Dann, Environment Canada, personal communication.

contribute substantially to haze and the associated degradation of visibility in urban areas. The smallest inhalable particles, those less than 2.5 µm in diameter, are of special concern because they may contain a wide range of toxic metals and chemicals as well as acid-forming sulphates and nitrates.

Human-induced particulate pollution occurs primarily in larger cities, where industries, motor vehicles, heating plants, and residential furnaces provide many emission sources. Smaller centres and rural areas may also experience unacceptable levels of particulate pollution as a result of emissions from industrial sources such as pulp mills or smelters or as a consequence of other activities such as transportation, agriculture, and forestry. In British Columbia, Yukon, Quebec, and the Atlantic provinces, wood smoke from the burning of logging or sawmill waste and from the use of wood for home heating is a common source of pollution (Haliniak and Schwartzel 1992). In these areas, particulate pollution sometimes occurs in winter because of increased heating demands and the more frequent formation of temperature inversions, beneath which contaminants are confined.

Particulate pollution is a seasonal problem in the Arctic. Known as Arctic haze, it occurs in winter and early spring, when conditions favour the transport of contaminants to, and their retention in, the Arctic atmosphere. These contaminants originate primarily in the industrial regions of Asia, Europe, and North America and are transported poleward by prevailing winds. Once the contaminants reach the Arctic, factors such as lack of sunlight, cold, stable air, and low precipitation combine to prolong their atmospheric lifetime (Barrie et al. 1992; see also Chapter 9 for further discussion of Arctic haze).

Figure 10.3
Particulate emissions by source, 1970–1990



Note: The methodology for the five major sectors differs for 1970–1980, 1985, and 1990. Each succeeding methodology represents a significant refinement in the number of sources and the emission factors used.

Source: Pollution Data Branch database, Environmental Protection Service, Environment Canada.

Industrial pollution controls, paving of dirt roads, improvements in energy efficiency, cleaner burner technologies, and increased use of cleaner-burning fuels such as natural gas have helped to reduce particulate emissions over the last 20–25 years (Fig. 10.3). In fact, the NAAQOs for particulates were exceeded fewer times between 1990 and 1992 than over the previous decade (see Chapter 12, Fig. 12.9), although economic recession and the cool, wet summer of 1992 in eastern North America likely share some of the credit for this improvement.

Further reductions in particulate emissions can be expected to result from other pollution control initiatives such as the NOx/VOC management plan and energy efficiency measures contained in the National Action Program on Climate Change (see Chapter 15). Significant emission reductions are being achieved by industry working cooperatively with governments. In addition, many communities have instituted "no burn" days or other restrictions to limit wood smoke emissions when weather conditions are unfavourable (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993).

Toxic air pollutants

The term "toxic air pollutants" is generally used to describe airborne substances that, depending on their concentration in plants and animals (including humans), can cause cancer, birth defects, organ damage, disorders of the nervous system, or other health effects. Substances of greatest concern are those that are persistent in the environment and accumulate in living tissue. Even small concentrations of these substances in the environment may have a harmful effect on organisms that are exposed to them, especially for a long period of time (see Chapter 13). The effect will depend on the concentration and a species' ability to adapt.

Persistent bioaccumulative substances, as these pollutants are known, can be anthropogenic or natural in origin. They include some metallic compounds (e.g., of lead, mercury, and cadmium) and a variety of volatile and semivolatile organic compounds. Some of these are released to the air directly as vapours; others are emitted

bound to the surfaces of fine particles; still others are naturally present in or are released to other media and cycle between components of the environment.

During the 1960s, concerns were raised about dichlorodiphenyltrichloroethane (DDT) and other organochlorine pesticides, mercury, tetraethyl lead, and polychlorinated biphenyls (PCBs). Except for lead, the atmosphere is not a major pathway of direct human exposure to this particular group of contaminants, but it is an important medium for transporting them to other environmental components such as water, where they may accumulate to dangerous levels in fish and other wildlife. It is estimated that Lake Ontario, for example, currently receives more than 500 kg of mercury from all atmospheric sources (anthropogenic plus natural) every year (Schroeder 1996).

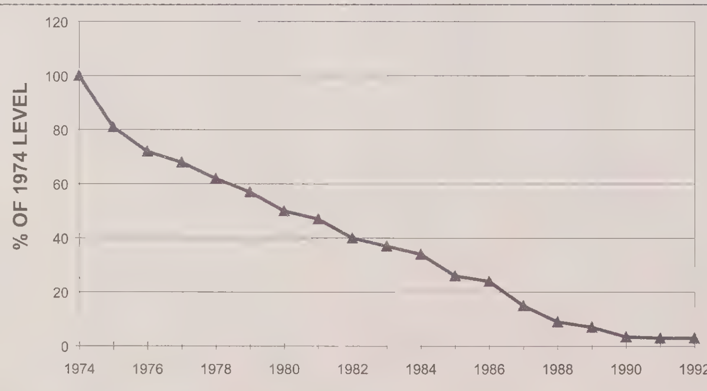
During the 1970s and 1980s, Canada, the United States, and several other industrialized nations moved to reduce or eliminate the use of a number of these substances. Several organochlorine pesticides were phased out of use, as was leaded gasoline. The manufacture of PCBs in North America was stopped, and the industrial use of mercury was vastly reduced.

The phasing out of leaded gasoline (for all but a few restricted uses) between 1974 and 1990 was by far the most successful of these initiatives. As Figure 10.4 illustrates, average concentrations of lead in ambient air have declined to a small percentage of their 1974 level.

Some of the semivolatile substances, such as mercury, PCBs, and organochlorine pesticides, however, continue to be recycled within the environment, through natural processes, long after their release. Warm weather causes them to evaporate from soils and water and be carried along by the wind. Eventually they return to the surface, either through direct deposition or after condensing onto airborne particles. This process will repeat itself many times. As the substances are transported towards polar regions, however, the possibility of evaporation diminishes because of lower temperatures. Consequently, these substances tend to accumulate more than might be expected in polar and subpolar regions (Barrie et al. 1992; Mackay and Wania 1995).

The observation that toxic effects could be produced by even minute residues of substances such as DDT or PCBs in the environment has naturally raised questions about many other widely used materials. These questions are extremely difficult to answer, as there are thousands of substances in common use and as, for the most part, little is known about their toxic potential within the environment. Laboratory studies can provide some indication of toxic effects, but the exposures are dependent on many, largely unknown properties of the substances and the environment. Long-term epidemiological studies are needed to establish the degree of risk associated with environmental levels of exposure.

Figure 10.4
National trend in ambient concentrations of lead, 1974–1992



Source: Pollution Data Branch database, Environmental Protection Service, Environment Canada.

At present, about 200 airborne substances have been identified as environmentally hazardous or potentially hazardous. These are substances that are already known or suspected to have some toxic characteristics, that are prevalent in the environment, and that may also bioaccumulate. Some of these are solvents, such as tetrachloroethylene (used in dry cleaning) and dichloromethane (a degreasing agent). These compounds are among the more volatile of those observed in the environment. Others are formerly used compounds such as PCBs, potential by-products of incomplete combustion such as polycyclic aromatic hydrocarbons (PAHs), potential by-products of certain industrial processes, notably polychlorinated dioxins and furans, and pesticides applied to the environment.

To determine which of these substances pose a toxic risk, the federal government established a Priority Substances List under the *Canadian Environmental Protection Act* (CEPA) in 1989. Assessment of the 44 substances on the list was completed in 1994. Of those 44 substances, 25 were determined to be toxic (according to the CEPA definition of "toxic"). Air is an important medium of transport for 15 of them. A second list, identifying 25 substances that will be given priority for scientific assessment, was published in December 1995.

Several working groups involving government and other interested parties are now examining ways of controlling emissions of CEPA toxic substances. A number of alternatives are being considered, including formal regulations or guidelines, voluntary agreements, and economic instruments. It is expected that the first recommendations will be made to the Ministers of Health and of the Environment in 1996.

These efforts are also being supported by the initiation of the National Pollutants Release Inventory (NPRI), which provides information on sources of toxic air pollutants (Environment Canada 1995a). The continuing work of the provinces' and Environment Canada's Measurement Program for Toxic Contaminants in Canadian Urban Air, which monitors concentrations of nearly 200 different air pollutants at selected sites across Canada, also bolsters these control efforts.

Table 10.3 shows average outdoor air concentrations of some of these substances in several Canadian localities. Generally, concentrations in cities are between 2 and 10 times greater than in rural areas, although a few industrial sites have high concentrations. The Jonquière site, for example, which is located near an aluminum smelter, recorded very high concentrations of benzo(a)pyrene (a PAH compound). However, much remains to be learned about the long-term toxic effects of these substances within the environment, and it cannot yet be said with certainty what concentrations of any of these substances can be considered an acceptable risk. It should also be noted that indoor air, workplace fumes, and tobacco smoke constitute a greater source of exposure to many toxic substances than outdoor air.

Average concentrations of the substances shown in Table 10.3 for the most part decreased between 1989 and 1993. Some of these reductions can be attributed to cleaner-running, more energy-efficient cars, cleaner industrial processes, and the temporary effects of economic recession.

Further reductions in emissions of some toxic VOCs should be achieved by 2005 as a result of measures in the NOx/VOC management plan (CCME 1990).

Efforts are also under way to decrease emissions of some toxic substances through voluntary measures. The Accelerated Reduction/Elimination of Toxic Substances (ARET) program, backed by industry, health, and professional associations as well as the federal and provincial governments, has targeted more than 100 substances for either virtual elimination of discharges or reduction to levels that are insufficient to cause harm. More than 160 organizations had submitted action plans by the end of 1995.

Table 10.3

Average ambient concentrations of selected toxic air pollutants in Canadian localities, 1989 and 1993

	Benzene (μg/m³)		Tetrachloroethylene (μg/m³)		Dichloromethane (μg/m³)		Formaldehyde (μg/m³)		Benzo(a)pyrene (ng/m³)		PCDD/PCDF TEQ[a] (pg/m³)	
Location	**1989**	**1993**	**1989**	**1993**	**1989**	**1993**	**1989**	**1993**	**1989**	**1993**	**1989**	**1993**
Urban												
Halifax, N.S.	–	4.1	–	1.0	–	0.8	–	–	–	–	–	–
Saint John, N.B.	–	1.7	–	0.2	–	0.9	–	1.7	–	–	–	–
Montreal, Que.	5.5	4.0	1.0	0.8	3.3	1.9	3.5	2.9	0.5	0.4	–	–
Ottawa, Ont.	5.1	4.0	5.6	2.7	–	2.2	3.3	5.6	–	–	–	–
Toronto, Ont.	3.3	2.1	0.9	0.9	3.5	1.8	2.9	2.3	0.2	0.2	–	–
Hamilton, Ont.	4.6	4.3	5.4	0.8	2.7	2.6	–	–	1.1	1.1	–	–
Sarnia, Ont.	4.9	2.6	0.4	0.2	1.3	1.0	–	–	–	–	–	–
Windsor, Ont.	3.2	2.4	1.2	0.6	1.9	1.1	2.8	3.5	0.5	0.4	0.195	0.059
Winnipeg, Man.	–	2.1	–	0.5	–	1.9	–	–	–	–	–	–
Edmonton, Alta.	–	3.6	–	0.8	–	1.4	–	–	–	–	–	–
Calgary, Alta.	–	3.4	–	0.9	–	0.6	–	–	–	–	–	–
Vancouver, B.C.	6.1	4.7	0.6	0.7	3.4	1.4	2.9	3.0	–	–	–	–
Industrial												
Jonquière, Que.	–	–	–	–	–	–	–	–	33.6	6.9	–	–
Rural												
Walpole Island, Ont.	1.2	0.8	0.3	0.2	–	0.6	–	–	0.1	0.0	0.034	0.031
Longwoods, Ont.	–	0.8	–	0.1	–	0.9	–	–	–	–	–	–
Remote												
Point Lepreau, N.B.	–	0.4	–	0.1	–	0.5	–	–	–	–	–	–
Ste. Françoise, Que.	–	0.6	–	0.1	–	0.4	–	–	–	–	–	–

[a] Total polychlorinated dioxins and furans (of which there are more than 200 varieties) are expressed in terms of the equivalent concentration, or toxic equivalent (TEQ), of the most toxic variety, 2,3,7,8-TCDD.

Source: T. Dann, Environment Canada, personal communication.

Acidic deposition

The phenomenon of acidic deposition — or, as it is more popularly known, "acid rain" — begins with emissions of sulphur dioxide and nitrogen oxides to the atmosphere. The main sources of these pollutants are the smelting of sulphur-bearing metal ores and the burning of fossil fuels. These acid-forming substances can return to the surface directly as gases or as sulphates or nitrates associated with particles. This is known as dry deposition. Alternatively, they can combine with water to form sulphuric and nitric acids that fall as precipitation (wet deposition). Because they can be carried hundreds of kilometres by atmospheric currents, acidic pollutants can settle in remote environments far from obvious sources of pollution.

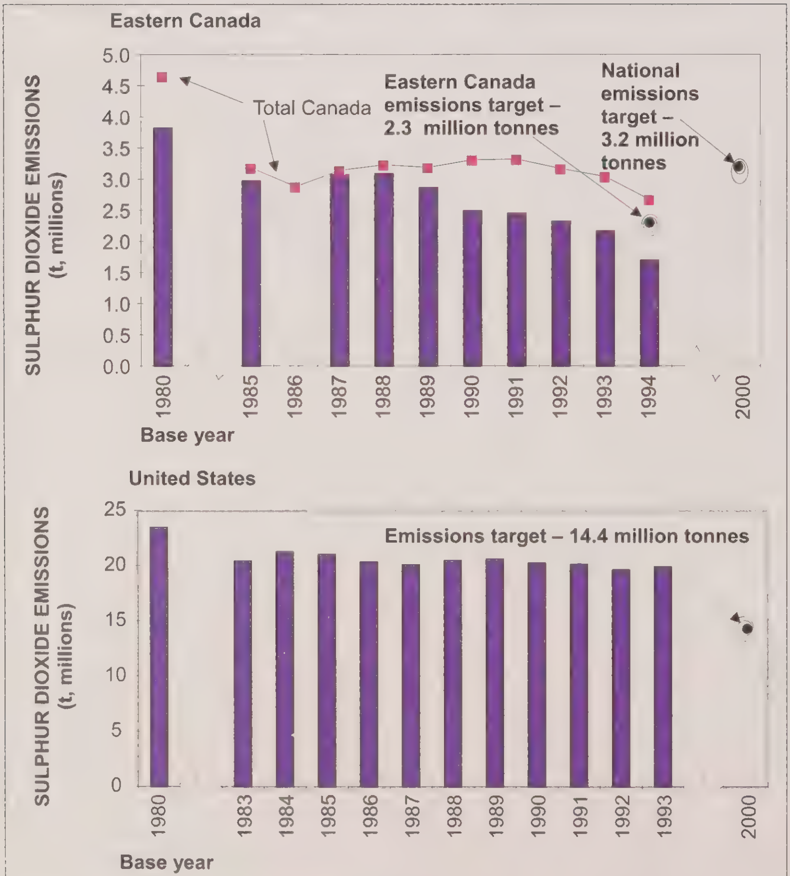
Acid-forming gases and particles have been linked to a variety of impacts, including forest decline, accelerated leaching of metals, some of whose compounds are toxic, from rocks and soils, the decay of limestone, marble, and other building materials, and damage to the human respiratory system. Regarding health effects, for example, recent research has revealed a strong relationship between lung function and long-term exposure to airborne acidity in children between the ages of 8 and 12. But the best-known and most thoroughly documented impact of acid-forming gases is their effect on freshwater ecosystems (see the "Fresh water" segment of this chapter). As lakes and rivers acidify, their ability to support many forms of aquatic life diminishes. It has been estimated that there are more than 14 000 acidic lakes east of the Manitoba–Ontario border and south of James Bay, and this figure takes into account only those lakes larger than 1 ha in size (RMCC 1990).

The Canadian Shield region of eastern Canada is particularly vulnerable to acidic deposition, because its thin soils and granitic bedrock have little natural capacity for neutralizing acids. The numerous lakes in this region are also downwind of several major sources of acidic gases, particularly smelters in northern Manitoba, Ontario, and Quebec and thermal generating stations in the United States, Ontario, New Brunswick, and Nova Scotia.

Attempts to reduce acidic deposition in eastern Canada have focused on the reduction of sulphur dioxide emissions, partly because sulphur dioxide has been a much greater contributor to acidification than nitrogen oxides and partly because sulphur dioxide emissions come mostly from a few large point sources and are therefore easier to control.

On average, annual sulphur dioxide emissions have declined gradually since the early 1980s (Fig. 10.5). In 1985, the federal government and the governments of the seven easternmost provinces agreed to reduce emissions east of the Saskatchewan border to 2.3 million tonnes a year by 1994. This target was surpassed when 1994 emissions in eastern Canada totalled 1.7 million tonnes. The target was intended to reduce wet sulphate deposition in eastern Canada to a maximum of 20 kg/ha per year — a level that available analyses indicated would, when combined with U.S. reductions, protect moderately sensitive aquatic environments from acidification (RMCC 1990). Highly sensitive aquatic ecosystems are not protected by this target.

Figure 10.5
Canadian and U.S. sulphur dioxide emissions and targets



Source: *Canadian data:* Environment Canada (1990, 1991, 1994d); *U.S. data:* U.S. Environmental Protection Agency (1994).

The U.S. government has also made commitments to reduce annual sulphur dioxide emissions by about 10 million tonnes below the 1980 level by the year 2000 and then to cap utility and industrial emissions at a combined total of 13.1 million tonnes by 2010. Canada has committed itself to hold the target for eastern Canadian emissions at the present 2.3 million tonnes to the year 2000 and to cap national emissions at 3.2 million tonnes by 2000. The trends shown in Figure 10.5 indicate that both these targets should be met.

As a result of reductions achieved so far, the area receiving sulphate deposition of more than 20 kg/ha per year has decreased substantially (Fig. 10.6). With further reductions in U.S. emissions, these decreases should continue over the next decade and a half.

Even after sulphate deposition is reduced, reversing the effects of acidification may take time. Our understanding of the combined effects of natural and human influences on the chemistry of aquatic ecosystems is far from complete. As an illustration, of 202 lakes examined in southeastern Canada between 1981 and 1994, some showed declining acidity, some showed stable acidity, and some showed increasing acidity (see Fig 10.16 in the "Fresh water" segment of this chapter). Local conditions, such as an excess of sulphate in soils or a shortage of acid-neutralizing agents like calcium and magnesium carbonates, have a considerable effect on how individual lakes respond. Ironically, such environmentally desirable practices as conservation tillage on farms and the use of precipitators to remove fly ash from industrial smokestack emissions may be reducing the supply of acid-buffering particulate matter to lakes and soils. The paving of country roads, which has increased in recent decades, has also had the same effect.

An important problem is what to do about areas that continue to be acidic even after deposition targets are reached. Waters in some particularly sensitive parts of Ontario, Quebec, New Brunswick, Nova Scotia, and southern Newfoundland, for example, are expected to show little improvement, even though wet sulphate deposition in these areas is likely to fall below 14 kg/ha per year once both Canadian and U.S. control programs are fully implemented (RMCC 1990). Canada is now working on a new National Strategy on Acid Rain to deal with the problem of these sensitive areas.

The new strategy may also have to consider the role of nitrogen compounds such as nitrogen oxides and nitrates in acidification. Some of the variation in the way lakes are responding to reduced sulphate deposition may be due to those compounds. Nitrogen oxide emissions have remained relatively stable throughout the 1980s and 1990s; nitrogen is a nutrient, and most Canadian ecosystems have been able to absorb it without any increase in nitrogen-related acidity. Their capacity to do so, however, may be approaching saturation. If that occurs, then further reductions of nitrogen oxide emissions — beyond the 10% called for in the NOx/VOC management plan — may be necessary.

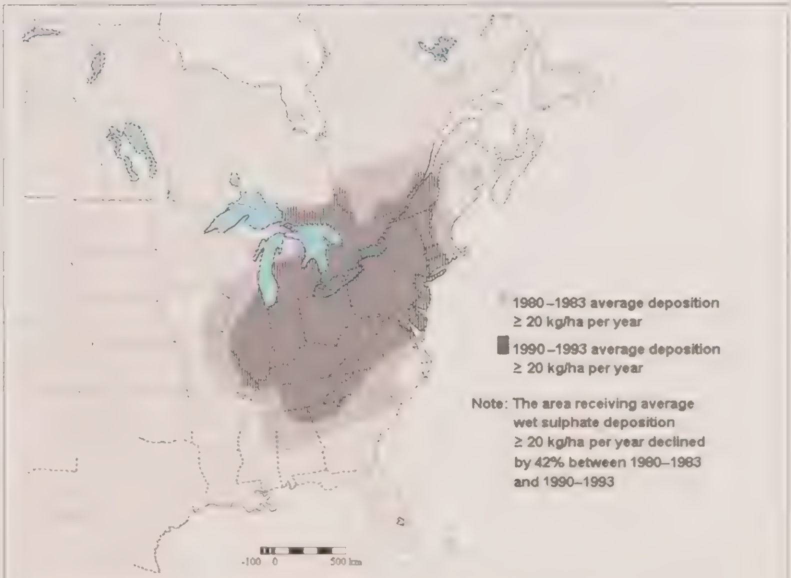
Stratospheric ozone depletion

Between 1980 and 1994, the concentration of stratospheric ozone declined by about 5–6% over southern Canada and by 7–8% over the north (Fig. 10.7(a); see also Chapter 15). This is part of a global phenomenon (Fig. 10.7(b)) that includes the seasonal formation of so-called "ozone holes" over Antarctica. First recognized in the mid-1970s, stratospheric ozone loss has been linked to several widely used chlorine and bromine compounds. CFCs are the most abundant of these, but other substances, such as halons, carbon tetrachloride, methyl chloroform, and methyl bromide, are also significant ozone-depleting compounds.

Because ozone is a major absorber of ultraviolet radiation, particularly the more energetic UV-B wavelengths, stratospheric ozone depletion leads to an increase in the amount of ultraviolet radiation reaching the Earth's surface (Kerr and McElroy 1993). Ultraviolet radiation from the sun is

Figure 10.6

Area receiving average wet sulphate deposition ≥20 kg/ha per year, for the periods 1980–1983 and 1990–1993



Source: Data supplied by Measurements and Analysis Division, Atmospheric Environment Service, Environment Canada, State of the Environment Directorate, Environment Canada

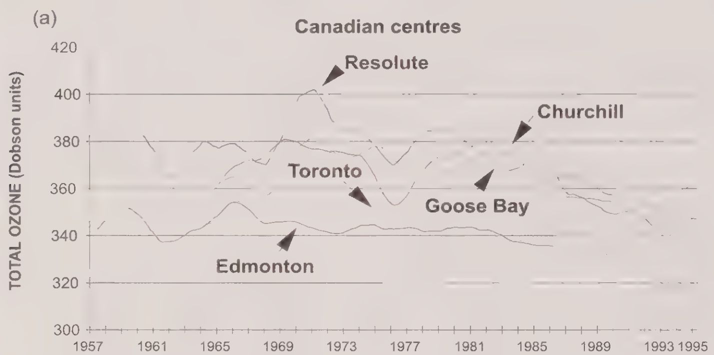
powerful enough to break strong chemical bonds and initiate chemical changes in materials and living cells. Exposure to excessive levels of ultraviolet radiation can therefore accelerate the degradation of common materials like wood, rubber, and plastic. Of greater concern, however, are its biological effects. High levels of ultraviolet radiation are known to slow plant growth and increase susceptibility to skin cancers, cataracts, and immunosuppressive diseases in humans and other animals (see Chapter 15 and the "Fresh water" segment of this chapter).

Compared with tropical and subtropical countries, Canada is exposed to relatively low levels of ultraviolet radiation. Stratospheric ozone is denser over middle and high latitudes than in the tropics, and the lower angle of the sun's rays also helps to diminish our exposure to ultraviolet radiation in certain seasons. However, having evolved under such conditions, indigenous life-forms may not be as well adapted as tropical species to withstand higher levels of ultraviolet radiation, and some species could suffer disproportionately from increased UV-B levels. This is particularly true in the Arctic, where there is a possibility of major ozone depletions in the spring, similar to the recurring ozone holes in the Antarctic. Mountain plants and animals as well as plankton communities that dwell on ocean and lake surfaces also face higher risks because they are exposed to more intense ultraviolet radiation levels.

Stratospheric ozone amounts over Canada reached their lowest observed levels yet in 1993, when they averaged 14% below pre-1980 levels for January to April and 7% below normal for the summer months (Environment Canada 1994a). This enhanced depletion of ozone was attributed to volcanic debris in the stratosphere from the eruption of Mount Pinatubo in 1991. For the first six months of 1995, total stratospheric ozone levels in Canada were 9.5% below normal (Environment Canada 1995b). In summer 1995, the Canadian average ozone depletion was 6.2%. Meteorological variation is the likely cause of the year-to-year irregularity in seasonal stratospheric ozone levels.

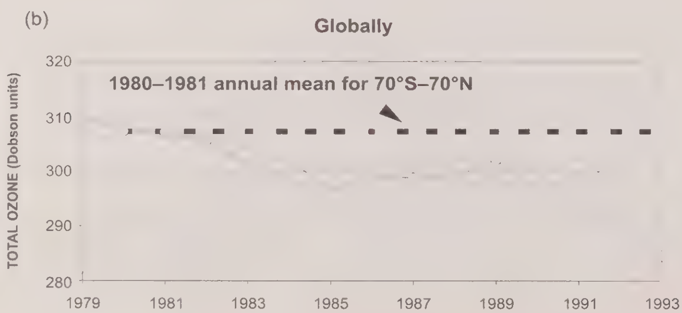
World production of ozone-depleting substances has decreased rapidly since the signing of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and subsequent agreements phasing out their production and use. If emissions of these substances continue to decline as forecast, then stratospheric ozone should begin to recover sometime early in the next century. However, this recovery is unlikely to be complete until approximately 2050 (WMO 1994). In Canada, all internationally agreed targets are being met; in some cases, national targets are even stricter. While most provinces are making efforts to phase out production and use, further efforts are likely to be necessary to ensure that existing CFCs are not released into the atmosphere and that regulations are strictly enforced.

Figure 10.7
Stratospheric ozone levels over selected Canadian centres and globally



Notes: (a) Measured by Brewer ozone spectrophotometer from the ground; 1994 measurements use data from January to August.
(b) This graph represents long-term trends in Canadian stratospheric ozone levels. The effect of short-term seasonal variations and quasi-biennial oscillations of stratospheric wind patterns has been largely removed by statistical smoothing.
(c) Dobson unit (DU) is the unit usually used to measure the thickness of ozone in the atmosphere. One DU is equivalent to a layer of pure ozone 0.01 mm thick at standard temperature (15°C) and pressure (101.3 kPa), spread over the surface of the Earth.

Source: Atmospheric Environment Service, Environment Canada.



Note: Measured by the Total Ozone Mapping Spectrometer (TOMS) on the Nimbus-7 satellite

Source: Laboratory for Atmospheres, National Aeronautics and Space Administration (NASA), Goddard Space Flight Center, Greenbelt, Maryland.

As yet, there is no evidence of biological damage that can be linked unequivocally to stratospheric ozone depletion over Canada (see Chapter 15). However, with several decades of below-normal ozone levels yet to come, it is still too early to know whether Canadians and Canadian ecosystems are being seriously affected.

Climate change

Heat-retaining greenhouse gases have a considerable effect on the Earth's climate. Since the industrial revolution, and especially during the past half century, human activities have caused a substantial increase in atmospheric concentrations of some of these gases — 30% for carbon dioxide and 145% for methane. In addition, synthetic substances with greenhouse gas properties, such as CFCs, have also been introduced to the atmosphere. Most climatologists agree that such increases could lead to major alterations in global and regional climates. (See Chapter 15 for further information. As well, for more information on the possible impact of climate change on land, fresh water, oceans, or wildlife, see the appropriate segments of this chapter.)

According to present scientific estimates, a doubling of atmospheric carbon dioxide, the most significant greenhouse gas associated with human activity, could eventually cause the planet's average surface temperature to increase by 1.5–4.5°C from preindustrial times. For Canada, some computer models estimate summertime increases in various parts of the country in the range of 2–4°C and wintertime increases of 4–10°C (Boer et al. 1992; Manabe and Stouffer 1994). However, models suggest and recent data indicate that temperature changes will be far from uniform over the globe and over Canadian territory, particularly when local cooling effects of acidic aerosols are factored in.

The impacts of such increases could be considerable. Not only would temperatures become warmer on average, but the amount and distribution of rain and snowfall would change. Some of these changes would be beneficial for Canadians. Longer growing seasons could benefit agriculture, and milder winters would lower home heating expenses.

On the other side of the ledger, energy demand for air conditioning would rise in summer. It has also been suggested that the frequency and severity of extreme events such as droughts, severe storms, and heat spells would increase. Forests, especially boreal forests, might not be able to adjust and migrate rapidly enough. They would also be subject to new pests and more frequent fires, whereas changing temperature and moisture conditions would make some areas inhospitable to species now growing there. Canadians might also be affected by increases in heat and smog, as well as diseases that do not normally occur in temperate climates. Rising sea levels would increase flooding in a number of coastal communities, whereas changes to water supplies inland would affect the operation of hydroelectric facilities, shipping, municipal water supplies, and the value of lakefront properties.

Over the past century, most parts of Canada have shown noticeable warming. The

Figure 10.8

Trends in Canadian and global average air temperatures, 1895–1995

Source: *Canada*: Atmospheric Environment Service, Environment Canada.
Global: P.D. Jones and T.M.L. Wigley, University of East Anglia, Norwich, U.K., personal communication

average annual temperature of the country as a whole rose by 1.0°C between 1895 and 1995, in general accord with the global air temperature trend, which has risen about 0.5°C overall (Fig. 10.8). Regionally, the greatest amount of warming occurred in the Mackenzie Basin (as much as 1.8°C) and in a broad band continuing south through the Prairie provinces. Warming has been minimal, though, in the Atlantic region, and some cooling has occurred in the easternmost Arctic Archipelago and to the south of Hudson and James bays (Fig. 10.9). These regional trends are reasonably consistent with estimates of past increases in concentrations of greenhouse gases and regional aerosols.

Corroboration of widespread warming also comes from studies of lake ice, which show a tendency towards shorter ice seasons in most parts of the country, largely because of earlier spring breakups (Environment Canada 1995c). These changes are consistent with expectations of climate change, but it cannot yet be proven whether they are the result of increases in greenhouse gases or simply a consequence of natural climatic fluctuations.

In 1990, Canadian sources emitted 460 million tonnes of carbon dioxide (Jaques 1992), or about 2% of the world total. In 1991, Canada was the world's 13th largest emitter of greenhouse gases; on a per capita basis, Canadians stood 11th (World Resources Institute 1994). Canada's cold climate and the large distances between population centres account for some of these emissions, but our resource-based economy and lifestyle choices add greatly to our consumption of fossil fuels and, hence, to our emissions of greenhouse gases (Fig. 10.10). Disturbances of natural land cover through agriculture, forestry, urbanization, construction, and other human activities reduce the capacity of ecological processes to cleanse the atmosphere.

By ratifying the United Nations Framework Convention on Climate Change (1992), Canada, along with over 35 other Annex 1 signatory countries, aims to stabilize its net greenhouse gas emissions at 1990 levels by the year 2000. The National Action Program on Climate Change, which is based on consensus by federal, provincial, and territorial governments, sets out strategic directions that Canada will follow in pursuit of its stabilization objective and provides guidance for further actions beyond the year 2000. It highlights ongoing and enhanced activities, new measures, and measures under consideration for future implementation. Canada's progress in meeting its current commitment to stabilize greenhouse gas emissions will be reviewed regularly. The federal government will continue to work with provincial, territorial, and municipal governments and nongovernmental stakeholders to ensure that Canada is on track to meet its climate change commitment.

Figure 10.9
Regional temperature changes, 1895–1993

Source: Climate Research Branch, Atmospheric Environment Service, Environment Canada.

Clearing the air

Although it is convenient to put atmospheric problems into tidy compartments such as smog, acid rain, or climate change, many of these issues are in fact interconnected. Consider climate change and smog, for example. Because the formation of ground-level ozone depends in part on temperature, a warmer climate is more likely to promote ozone formation than a cooler one. And because ground-level ozone is also a greenhouse gas, increased ozone concentrations would provide further reinforcement for any warming trend.

As another illustration, sulphate particles in the atmosphere are harmful to the respiratory system and are the main cause of soil and water acidification. However, these particles also reflect sunlight and appear to be partially masking the warming effects of greenhouse gases in some areas of the world. In addition, while CFCs are powerful greenhouse gases, the depletion of stratospheric ozone, which they cause, tends to cool the climate slightly.

Moreover, environmental stresses rarely occur in isolation. A declining forest may be the victim not only of acid rain but also of one or more other stresses, such as ozone pollution, drought, increased ultra-

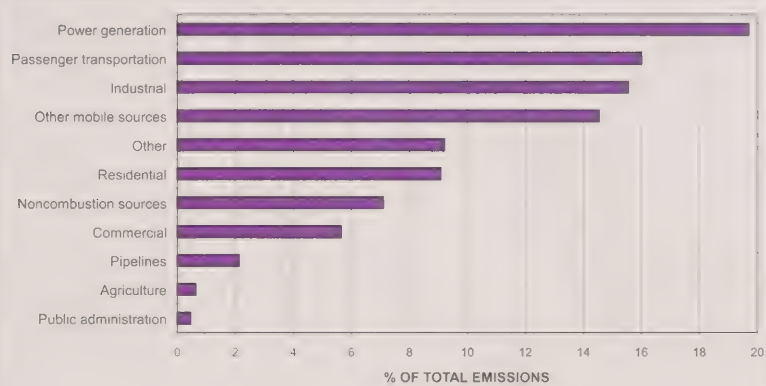
violet radiation, insect pests, fire, and diseases. Because of such relationships, it is not possible to deal with atmospheric issues in isolation from one another: the solution to one problem may give rise to problems of another kind. Instead, the relationships among these issues must be understood and solutions developed that deal with them collectively.

To deal with more than one environmental problem at a time, future control measures will inevitably be more complex and harder to devise. Finding these solutions will become more complicated for at least three other reasons as well. One is that the easiest gains — for example, the halving of sulphur dioxide emissions between 1980 and 1994 — have already been made. As Canada's population increases, making further gains or even preserving those already achieved may become increasingly difficult.

The second reason is that any comprehensive strategy for reducing air pollution will likely have to confront our reliance on fossil fuels for energy. Fossil fuels are major contributors to smog, acidic deposition, toxic pollutants, and climate change. However, because our whole way of life depends on their use, decreasing this reliance is not likely to be easy. It may well depend on social modifications, such as improving the efficiency of energy uses, changing modes of public and private transportation, and making our cities more compact, as well as on new technologies and alternative energy sources.

The third reason is that many of these problems are regional or supranational in scope. The wind recognizes no boundaries, and the reduction of atmospheric pollution often requires the cooperation of various jurisdictions and countries, including developing countries, or of the world as a whole. As a result, efforts to improve air quality will increasingly have to have an international and socioeconomic as well as a technological dimension.

Figure 10.10
Canadian carbon dioxide emissions by sector, 1993



Source: A.P. Jaques, Environmental Protection Service, Environment Canada, personal communication.

Table 10.4
Land and freshwater areas, by province/territory

Province/territory	Land area (km²)	Freshwater area (km²)	Total area (km²)	% of total area
Newfoundland	371 690	34 030	405 720	4.1
Prince Edward Island	5 660	0	5 660	0.1
Nova Scotia	52 840	2 650	55 490	0.6
New Brunswick	72 090	1 350	73 440	0.7
Quebec	1 356 790	183 890	1 540 680	15.5
Ontario	891 190	177 390	1 068 580	10.7
Manitoba	548 360	101 590	649 950	6.5
Saskatchewan	570 700	81 630	652 330	6.5
Alberta	644 390	16 800	661 190	6.6
British Columbia	929 730	18 070	947 800	9.5
Yukon	478 970	4 480	483 450	4.8
Northwest Territories	3 293 020	133 300	3 426 320	34.4
Canada	9 215 430	755 180	9 970 610	100.0

Source: Statistics Canada (1994b).

Land

Geographical context

Canada is a land of extremes and of contrasts. Its surface area (land plus fresh water) of 9 970 610 km² (see Table 10.4) occupies 7% of the world's land mass and is second only to that of the Russian Federation. As the crow flies, Canada extends roughly 5 300 km east to west, from St. John's, Newfoundland, to the Queen Charlotte Islands in British Columbia, and nearly 4 600 km south to north, from Point Pelee in southern Ontario to Alert on Ellesmere Island in the high Arctic. Canada's coastline of 243 792 km is the longest in the world.

Despite its vastness, the country supports only a relatively modest population: 29.7 million in 1995 (B. Mitchell, Statistics Canada, personal communication), or 0.5% of the world's people. Average population density is low — about 3.0 persons per square kilometre — but this figure is misleading, as the population is highly concentrated in major urban areas in the south. About 80% of Canadians live in urban areas, which cover only 0.2% of the

country, and nearly 60% of Canada's urban population lives in centres of 500 000 or more (see Chapter 12).

Covering half a continent, the country has a wide range of landscapes and encompasses several distinct ecological zones. The diversity of physical and biological features can be categorized in various ways. Figure II.2 (in the Introduction to Part II) illustrates one such categorization — by ecozones — and Tables II.1 and II.2 outline some of the physical, biological, and land use characteristics associated with each of these ecozones.

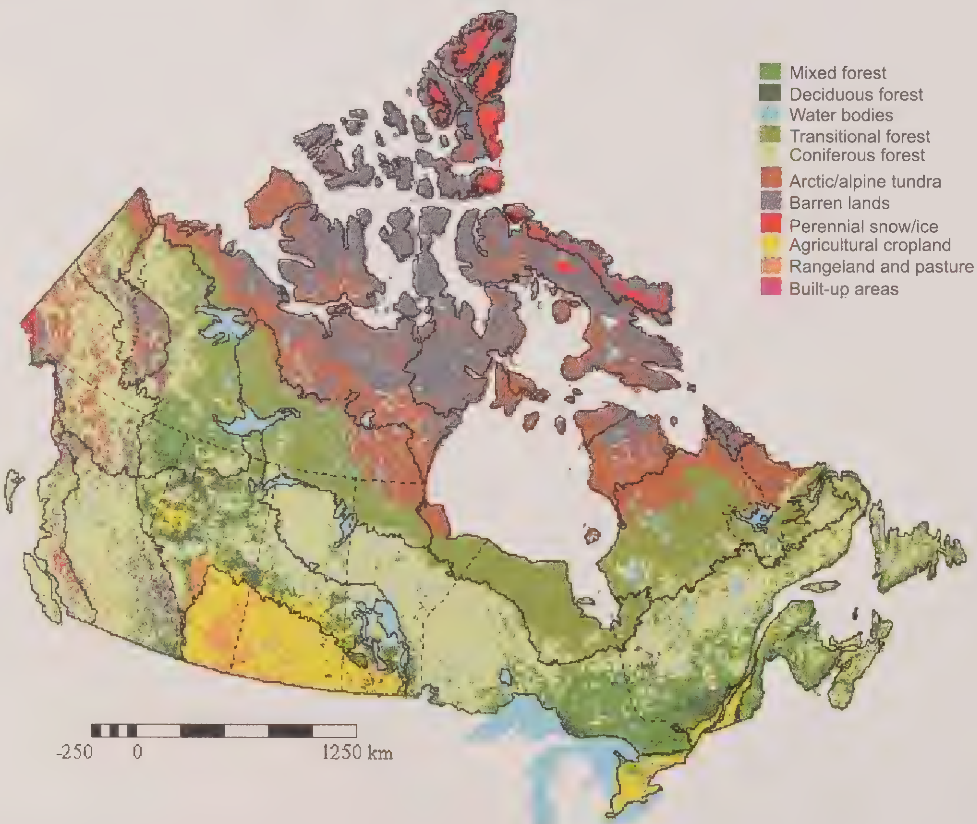
Because of the great diversity in climates, landforms, vegetation, mineral and hydrocarbon resources, and economic activities, environmental stresses vary considerably across the country. In the boreal ecozones, ensuring sustainable use of forests and mineral resources is a chief concern. In agricultural and urban-based ecozones, such as the Prairies, the Mixedwood Plains, and parts of the Pacific Maritime and Montane Cordillera ecozones, concerns include water quality, urban congestion, loss of wildlife habitat and farmland, and air pollution. On both coasts, declining fish stocks and concerns over forestry practices are also significant. In the Arctic, the contamination of wild food sources by toxic substances is a prime concern (Government of Canada 1991b).

More than any other industrialized nation, Canada depends on the land for its economic well-being. One in three workers is employed directly or indirectly in agriculture, forestry, mining, energy, or other land-based activity. Each year, these same activities account for approximately half of the value of exports. Beyond its significance to the economy, Canada's land — its quality and diversity — is closely linked to our sense of national identity.

Land cover of Canada

Figure 10.11 depicts the land cover of Canada against a background of the country's 15 terrestrial ecozones. The map shows 11 classes of land cover, including a differentia-

Figure 10.11
Land cover of Canada



Source: State of the Environment Directorate, Environment Canada.

tion among the major forest types. Table 10.5 shows the percentage of Canada's area within 10 of the 11 classes (water bodies have not been included), by ecozone.

Wetlands merit special mention here. Wetlands are lands that have the water table at, near, or above the land surface or that are saturated for extended periods. Altogether, they comprise 14% of Canada's area — an estimated 1.27 million square kilometres, which is nearly one-quarter of the world's wetlands. Wetlands are important ecosystems (see Box 10.1 in the "Fresh water" segment of this chapter) that bridge some of the different types of land cover portrayed in Figure 10.11. Figure 10.12 shows the distribution of wetlands in Canada on the ecozone map.

In earlier times, wetlands were often considered useless and were referred to as "wastelands." It was common practice to drain them or fill them in. Since European settlement, 70% of Pacific estuary marshes, including 80% in the Fraser River delta; 70% of central Prairie potholes; 68% of southern Ontario wetlands; and 65% of Atlantic coastal salt marshes have been lost or severely degraded (Rubec 1994). Large losses have also been reported for the original wetlands in the Montreal area of the St. Lawrence River (Champagne and Melançon 1995). On average, drainage for agriculture has accounted for about 85% of these losses, urbanization and industrial development for 9%, and leisure and recreation property expansion for 2% (Rubec 1994). The flooding of large areas for reservoirs for hydroelectric energy production and water level management has also contributed to wetland losses.

In March 1992, in an effort to help prevent further wetland losses, the Government of Canada released the Federal Policy on Wetland Conservation. The policy applies to wetlands on federally managed lands, which make up about 29% of Canada's wetland base. The provinces of

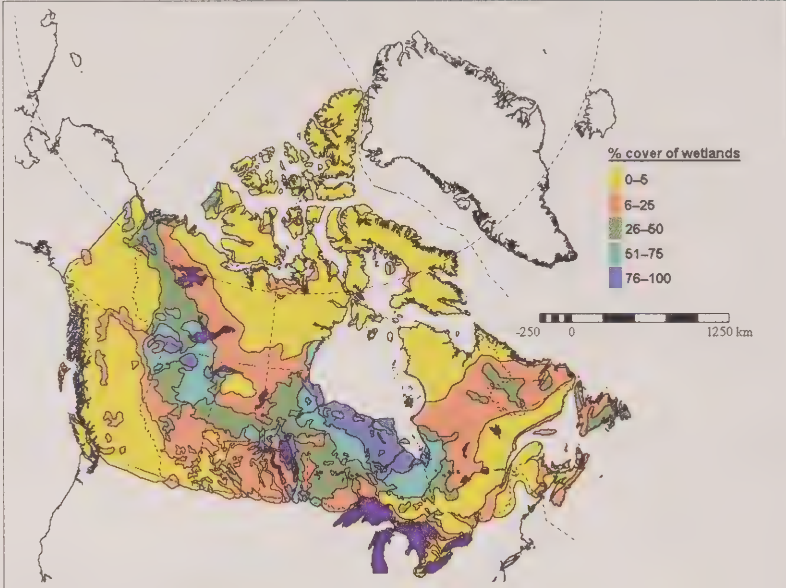
Figure 10.11 (continued)
Land cover of Canada

Land cover class	Definition
Forest	Land currently supporting or capable of growing forest, with tree crown cover of 10% or more. Includes land where trees are stunted owing to site limitations, undetectable owing to disturbance, or temporarily absent. Also includes extensive wetland areas.
Continuous forest • Coniferous • Deciduous • Mixed	Forestland occupies more than 50% of the area: • 76–100% of the canopy is composed of coniferous trees; • 76–100% of the canopy is composed of deciduous trees; • 26–75% of the canopy is composed of coniferous or deciduous trees.
Transitional forest	A mixture of land cover classes where tree cover is discernible, but forestland occupies less than 50% of the area. Tree density varies from open woodland to scattered groves of trees or linear forests in valleys. Understorey vegetation includes low, erect shrubs, dense lichen mats, and mossy peatland.
Arctic/alpine tundra	Treeless Arctic and alpine vegetation with nearly continuous plant cover. Includes low, erect, and matted shrub tundra and tussock cottongrass tundra in the southern Arctic (shrub component 25–75%); prostrate and matted shrub and herb tundra in the northern Arctic (shrub component 10–25%); and wetlands dominated by dense sedge–moss meadows.
Barren lands	Plant cover is generally sparse (<25%) and is not discernible from the imagery. Woody plants and herbs dominate most of the terrain, with scattered herbs and nonvascular plants in the northwestern sector of the Arctic Archipelago. Some dense lichen-dominated communities occur in Keewatin and southern Baffin Island. Totally unvegetated terrain includes sand, rock, and unconsolidated material.
Agricultural land	
Cropland	Cultivated land with crops, fallow, feedlots, orchards, vineyards, nurseries, shelterbelts, and hedgerows.
Rangeland and pasture	Land supporting native vegetation (shrubs, grass, and other herbaceous cover) with less than 10% tree cover. Includes improved land dedicated to the production of forage, as well as upland and lowland meadows.
Nonvegetated land	
Perennial snow or ice	Perennial snowfields and glaciers.
Built-up areas	Cities and towns of sufficient size to be depicted at the scale of mapping.
Water	
Water bodies	

Alberta, Saskatchewan, Ontario, New Brunswick, Nova Scotia, and Prince Edward Island have also developed or are developing wetland policies.

Land capability and productivity
Wise management of land depends on reliable information about its inherent quality and the extent of areas suitable for particular land uses. The Canada Land Inventory (CLI) provides a comprehensive assessment of renewable resource information for the southern, most heavily settled portions of Canada, covering all of the most productive lands, as well as areas where land use conflicts and losses might arise (Fig. 10.13). The principal component of the CLI consists of land capability ratings for five independently inventoried sectors: agriculture, forestry, wildlife: waterfowl, wildlife: ungulates, and outdoor recreation. There are seven classes for each of the five sectors. Table 10.6 shows prime CLI lands (classes 1–3) by use and jurisdiction for each sector except forestry, for which data were not available by

Figure 10.12
Distribution of wetlands in Canada



Source: National Atlas Information Service, Natural Resources Canada.

Table 10.5
Land cover of Canada, by ecozone

Terrestrial ecozone	% of ecozone									
	Mixed forest	Deciduous forest	Transitional forest	Coniferous forest	Arctic/ alpine tundra	Barren lands	Perennial snow or ice	Agricultural cropland	Rangeland and pasture	Built-up areas
Arctic Cordillera	0.0	0.0	0.0	0.0	4.3	43.6	52.0	0.0	0.0	0.0
Northern Arctic	0.0	0.0	0.0	0.0	23.4	74.2	2.4	0.0	0.0	0.0
Southern Arctic	0.0	0.0	5.0	0.1	58.3	36.6	0.0	0.0	0.0	0.0
Taiga Plains	28.5	4.8	26.5	35.5	3.6	1.1	0.0	0.0	0.0	0.0
Taiga Shield	1.6	0.0	57.8	12.7	26.9	1.0	0.0	0.0	0.0	0.0
Boreal Shield	28.9	4.5	5.1	60.2	0.0	0.8	0.0	0.5	0.0	0.1
Atlantic Maritime	49.3	12.2	0.4	27.9	0.0	1.2	0.0	8.8	0.0	0.2
Mixedwood Plains	22.2	3.7	0.0	0.4	0.0	0.1	0.0	71.7	0.0	1.9
Boreal Plains	25.5	20.0	0.1	38.5	0.0	0.0	0.0	12.7	3.2	0.1
Prairies	0.4	2.9	0.0	0.1	0.0	0.0	0.0	69.4	26.9	0.3
Taiga Cordillera	2.8	0.6	6.8	39.3	26.3	24.3	0.0	0.0	0.0	0.0
Boreal Cordillera	3.5	0.5	0.0	54.9	28.4	10.0	2.6	0.0	0.0	0.0
Pacific Maritime	13.1	0.5	0.2	60.9	0.5	13.7	10.3	0.4	0.0	0.4
Montane Cordillera	15.5	3.3	0.0	67.1	2.0	9.7	0.6	0.2	1.6	0.0
Hudson Plains	0.6	0.0	82.8	11.2	5.4	0.0	0.0	0.0	0.0	0.0
Canada	12.1	3.3	14.8	28.0	14.9	17.5	2.1	5.6	1.7	0.1

Note: Numbers may not add up owing to rounding; water bodies are not included.

Source: National Oceanic and Atmospheric Administration (NOAA), Advanced Very High Resolution Radiometer (AVHRR) imagery; Manitoba Remote Sensing Centre, Manitoba Department of Natural Resources; State of the Environment Directorate, Environment Canada.

Figure 10.13
Areas covered by the Canada Land Inventory

Source: Canada Land Inventory database, Environment Canada.

jurisdiction. Covering approximately 2.6 million square kilometres (about one-quarter of the country), the CLI is one of the largest land inventories ever undertaken in the world.

Examples of how the CLI has been used to assist in land use decision-making include the following:

- In British Columbia, prime agricultural lands comprise only 5% of the province's total area. These limited lands were long under pressure from competing uses. In the 1970s, the CLI was instrumental in helping the province and others move quickly to designate agricultural lands for protection.
- Analyses using the CLI agriculture and forestry components have demonstrated that more than 70% of eastern Canada's prime lands receive acidic deposits at levels threatening sustainable productivity.
- In support of the North American Waterfowl Management Plan (NAWMP), the CLI has helped to screen out areas where

Table 10.6
Prime Canada Land Inventory lands (classes 1–3) by use and jurisdiction

Land capability classes	CLI lands, by jurisdiction (ha)[a]											
	Nfld.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	Canada	% of total area[c]
Agriculture												
1	0	0	0	0	19 533	2 156 776	162 508	999 727	786 555	69 948	4 195 047	0.45
2	0	261 352	166 259	160 792	909 671	2 217 771	2 530 258	5 873 285	3 838 965	397 688	16 356 041	1.77
3	5 504	141 524	982 457	1 152 089	1 281 043	2 909 460	2 440 485	9 420 057	6 110 044	999 778	25 442 441	2.76
Recreation												
1	6 083	10 811	639	930	38 248	41 004	2 294	7 269	5 344	18 612	131 234	0.05
2	74 035	6 952	11 103	23 962	245 005	123 890	19 890	15 687	27 663	161 339	709 526	0.29
3	518 381	50 698	63 389	112 624	1 474 800	1 248 974	156 756	242 024	126 807	1 028 429	5 022 962	2.04
Wildlife ungulates												
1	504 680	b	148 766	575 521	1 207 803	0	764 204	428 532	3 671 453	2 870 295	10 171 254	4.39
2	2 698 123	b	235 643	867 285	11 854 045	4 217 024	2 850 350	2 956 864	5 204 164	5 652 262	36 535 760	15.77
3	3 531 061	b	1 307 550	2 569 073	4 948 122	2 853 813	4 591 281	13 395 901	10 220 002	7 731 968	51 148 771	22.07
Wildlife waterfowl												
1	b	127 899	318 494	260 691	667 925	1 176 493	625 499	771 574	264 261	461 176	4 674 012	[illegible]
2	b	1 981	1 418	8 545	6 407	4 449	508 600	3 194 162	2 539 295	52 235	6 317 092	2.56
3	b	173	14 118	28 032	28 098	82 627	869 742	4 886 871	2 139 821	131 691	8 181 173	[illegible]

[a] Yukon and Northwest Territories are not covered by the CLI.
[b] Not assessed.
[c] Percentage of all classes 1–7.

Source: Simpson-Lewis et al. (1979).

habitat maintenance would have conflicted with agricultural production.

Completed in the 1970s, the CLI continues to be a planning tool that makes a vital contribution to efforts to understand and resolve urgent environmental problems.

The CLI provides information on the long-term capabilities of land for particular uses. However, there are limited data on how the land is actually being used: how much of the land that is best suited for a particular use is currently being used for that purpose, and how much of it is even really available for that use. For example, about 460 000 km^2 are classified as prime (classes 1–3) agricultural land. Of this area, about 42 000 km^2, or less than 0.5% of Canada's total land area, are classified as class 1 agricultural capability, and just over half of this (51%) is in southern Ontario. It remains unclear as to how much of this prime agricultural land is actually being farmed and how much has been converted to urban and other uses. Another concern is that the CLI does not recognize that land classed as lower capability for production of cereals and oilseeds may be very important for forage and livestock production. Agriculture often loses land with high capability for forage and livestock to urban and industrial development simply because the land has a low CLI classification.

This quandary of capability versus actual use or availability for use also applies to the other four CLI sectors. For example, according to the CLI, Alberta contains 9 790 km^2 of lands with a high capability for Pronghorn (antelope), which is 73% of the national total (Environment Canada 1988). A large proportion of this area is unavailable as Pronghorn habitat because of agriculture and other land uses; however, forage-based agriculture does not necessarily exclude Pronghorns, and the majority of Pronghorns in south-central Alberta are in fact found on both private and public lands used for cattle production (L. Fullen, Food and Rural Development, Alberta Agriculture, personal communication). Currently, there is no national database of land capability versus actual use for the various sectors.

Major land uses

Another method of classifying land is by its use. Table 10.7 shows the predominant land uses and the area and percentage of Canada represented by each class. The principal land use sectors are forestry, recreation and conservation, agriculture, energy development, transportation, and all of the activities that are carried out in urban settings, including manufacturing and residential uses. Environmental issues arising from these various land use activities are discussed in Chapters 11 and 12, and regional perspectives are provided throughout Chapters 3–9.

Table 10.7
Land use in Canada

Land use class	Predominant activity in the class	Area[a] (km^2, 000s)	% of Canada[b]
Forestry[c]	Active forest harvesting or potential for future harvesting	2 440	24
Recreation and conservation[d]	Recreation and conservation within national, provincial, and territorial parks, wildlife reserves, sanctuaries, etc.	756	8
Agriculture[e]	Agriculture on improved farmland (cropland, improved pasture, summerfallow) and unimproved farmland	680	7
Urban	Built-up urban areas	20	<1
Other activities	Includes hunting and trapping, mining, energy developments, and transportation	6 074	61
Total		9 970	100

[a] Includes the area of all land and fresh water.
[b] Rounded to the nearest percent.
[c] Canadian Council of Forest Ministers (1995).
[d] National Conservation Areas Database, State of the Environment Directorate, Environment Canada.
[e] Statistics Canada (1994c).

Land use issues: recognizing the challenges

Expanding human needs and economic activities place ever-increasing pressures on land. This creates competition and conflicts, sometimes resulting in improper land uses. A disciplined approach to land use planning and environmental management crosses jurisdictional boundaries. Municipal, provincial, or even national boundaries have little relation to a unified bioregion or any kind of ecological entity. This may be obvious, but it makes cross-boundary planning difficult to undertake and implement. Canadians in every province and territory face major decisions regarding how to use and manage their natural resources. More and more people are recognizing the necessity of balancing competing demands on a limited land and resource base in order to maintain both a healthy environment and a prosperous economy. The issues are not easy: consider, for example, the controversy over forestry versus wilderness preservation in British Columbia, or Aboriginal uses versus recreational uses in various locations. Three challenges relate to the legacy of history, conflicting interests, and multilevel jurisdiction.

First, current land use patterns are a legacy of past decisions and reflect the country's social and economic history. But the patterns are not static. They evolve slowly through continuous, incremental changes — changes wrought by innumerable decisions made by governments, corporations, and individuals in response to shifting perceptions of the opportunities and constraints posed by the natural environment and dynamic social, economic, and technological forces.

Second, land use issues can affect interests ranging from purely local to national in scope. They take many forms and are addressed in many different forums — from debates in city council chambers over neighbourhood zoning bylaws to discussions in federal and provincial cabinets on resource development and conservation strategies. The issues encompass a wide range of concerns and have impacts that vary in their short-term and long-term social, economic, and environmental significance.

Finally, appropriate land use/management is not a single target that can be reached by a single decision or one piece of legislation. Rather, it should be the result of a chain of decisions involving the conscious design of the future human environment. However, at the present time, the existing administrative arrangements do not form an adequate decision-making system, which has been described as "a diverse and largely unrelated collection of procedures carried out under different pieces of legislation for which different provincial ministers are responsible" (Royal Commission on the Future of the Toronto Waterfront 1992). Because such decisions must balance diverse interests, no one government can make them all. The chain of decisions must involve all orders of government, in ways appropriate to their interests and responsibilities, as well as others who are interested in the land allocation and management process.

The Constitution gives the provincial governments jurisdiction over the management and control of land use within their jurisdictions. Nonetheless, federal policies, programs, and proprietary interests substantially affect land use and management throughout the nation and have a marked influence on the implementation of provincial land use strategies and plans.

Federal agricultural, forestry, energy, minerals and metals, transportation, housing, fiscal, and other policies influence what kind of economic activity will take place, and where, with implications for land use. Sectoral support programs improve the economic climate for certain industries and produce land use adjustments. Regional development programs aimed at reducing regional disparities accelerate the rate of land use change in the less developed areas of the country.

The use of federal regulatory powers also stimulates land use adjustments and changes. Parliament can directly regulate land use for specific purposes (e.g., to ensure safe and effective operations around airports). Finally, through a variety of research and information programs, the federal government produces information that can have profound impacts on the policies and programs of all orders of government and on decision-making in the private sector related to land use.

Parliament has legislative jurisdiction over land in Yukon and the Northwest Territories. In addition, land for Indian reserves and national parks falls under exclusive federal jurisdiction. Other federal land is used for airports, defence establishments, harbour sites, migratory bird sanctuaries, and government buildings. Some of these uses affect the use of surrounding private and provincial government lands. National parks, airports, harbour facilities, and railways, for example, greatly influence the use of adjacent land.

In spite of the complexities involved in studying and resolving land use issues, a myriad of land-related concerns can clearly be identified. Canadians in all walks of life, and their governments, are concerned about environmental quality, employment opportunities, economic growth, and the efficient use of resources. Land is a key factor in these concerns. Some of the principal land issues at present relate to the loss and changing use of prime agricultural land and forestlands, land degradation, the impact on land of government policies and programs, and the use of "hazard lands" (e.g., floodplains and eroding banks), including those where hazardous wastes are stored. The access to land for mineral exploration is also a concern, as outlined in the federal government's Mining Agenda. Moreover, concerns about the issue of climate change are primarily linked to its impact on land resource activities, such as forestry and agriculture (see Chapter 11).

Land tenure

Ownership patterns have a profound influence on land use planning in Canada. About 90% of the land is federally or provincially owned (see Table 10.8). The federal government, with 40%, is the country's single largest landowner, with the largest holdings being in Yukon and the Northwest Territories. Most Canadians, however, live on the 10% that is privately held.

The various orders of government all have roles in land use planning and management. The federal government and each province have constitutional authority over land use within their respective jurisdictions. Municipal authority is derived from the province, and, apart from provincial sufferance, municipal powers have no constitutional basis.

In Canada, there is a gap in perception about the role of land: it is often perceived in its cultural and economic role rather than its ecological role. However, this perception is gradually changing. Competition and conflict arise because, simply put, different people seek different benefits from the same area of land. The role of governments is apparent when the potential impacts of land use decisions go beyond the land area directly affected. For example, a new highway may entail environmental or socioeconomic costs nearby, such as drying up of wetlands or degradation of agricultural lands, but may bring benefits to people a considerable distance away (e.g., by providing access for tourists).

Good land use practices are important responsibilities of various councils of government ministers, such as those for agriculture, forestry, environment, and parks. Such councils reflect a coordinated approach to land use decision-making. They can take concerted action to achieve sustainable land use through improved scientific research, including the development of inventories, and infor-

mation initiatives to promote citizen awareness and action.

Aboriginal peoples

For many Aboriginal communities, resource development is an important way to achieve economic progress. Reserves and areas covered by land claim agreements provide Aboriginal people with effective control over agriculture and a diverse range of activities related to natural resources, including hunting, trapping, fishing, logging, tourism, and, in some instances, extraction of hydrocarbons and mining of materials both on the surface and underground. The Canadian Aboriginal Economic Development Strategy, commonly known as CAEDS, aims to ensure that Aboriginal communities benefit from such opportunities.

Aboriginal people have long maintained a special relationship with the land as the basis of their cultural distinctiveness and special status. Recognition of this relationship is a fundamental objective of the settlement of claims based on Aboriginal title. Land claim agreements and treaties assure First Nations and Inuit peoples certain rights to natural resources. Claims are of two basic types — comprehensive and specific.

Comprehensive claims

Comprehensive claims are based on Aboriginal title arising from traditional use and occupancy of land. They affect those parts of Canada where Aboriginal title has not been dealt with by treaty or other lawful means, including Yukon and Labrador, most of British Columbia, and parts of Quebec and the Northwest Territories. They normally involve Indian or Inuit groups (e.g., tribal councils, bands, or communities) that assert Aboriginal title to a specific geographic area. Settlement agreements include such elements as the establishment of ownership of land and resources, measures to stimulate economic development, the commitment to negotiate self-government, recognition of the continuing interest of Aboriginal groups in renewable resource management and environmental protection, and measures to ensure that Aboriginal groups share in the benefits of development (Department of Indian Affairs and Northern Development 1995a). Following are four examples of recent comprehensive claims agreements (Department of Indian Affairs and Northern Development 1993a, 1995b):

> *"In a country that owes so much of its national character to resource frontiers created by immigrant society, it is now Aboriginal people who advance into 'new territory' by reclaiming lands and resources as well as management power over them.... The newly evolving partnership between Aboriginal and non-Aboriginal resource users and managers may open up another frontier which both parties can advance together: towards more responsible and sustainable environmental management."*
>
> — Notzke (1994)

Table 10.8
Ownership of lands in Canada

Province/territory	Total area[a] (km²)	% of total area		
		Crown land		Private land[d]
		Federal[b]	Provincial or territorial[c]	
Newfoundland	371 690	0.7	94.9	4.4
Prince Edward Island	5 660	0.8	12.1	87.1
Nova Scotia	52 840	2.9	29.8	67.3
New Brunswick	72 090	3.0	42.9	54.1
Quebec	1 356 790	0.2	92.1	7.7
Ontario	891 190	0.9	88.0	11.1
Manitoba	548 360	0.8	78.0	21.2
Saskatchewan	570 700	2.4	59.7	37.9
Alberta	644 390	9.6	62.6	27.8
British Columbia	929 730	0.9	93.3	5.8
Yukon	478 970	99.8	0.2	<0.1
Northwest Territories	3 293 020	88.4	0.1	11.5
Canada	9 215 430	40.3	50.0	9.7

[a] All figures have been rounded.
[b] Includes federal Crown lands, national parks, and federal forest experimental stations.
[c] Includes provincial or territorial areas, provincial parks, and provincial forests.
[d] Includes privately owned land or land in the process of alienation from the Crown.

Source: State of the Environment Directorate, Environment Canada.

Gwich'in Comprehensive Land Claim Agreement: This agreement, which received Royal Assent on 22 December 1992, provides the Gwich'in with approximately 24 000 km² of land (4 299 km² of which includes mineral rights) in the Northwest Territories and Yukon. It also provides a tax-free payment of $75 million over 15 years, a share of resource royalties from the Mackenzie Valley, guaranteed wildlife harvesting rights, and participation in various decision-making bodies.

Final agreements with the Council for Yukon Indians and four Yukon First Nations: These agreements, which received Royal Assent on 29 May 1993, provide four Yukon First Nations with settlement land of 17 235 km², 12 613 km² of which include mines and minerals

(settlements with other Yukon First Nations have not yet been finalized). The agreements provide financial benefits of $79.9 million, rights in the management of national parks and wildlife areas, specific rights for fish and wildlife harvesting, and special economic and employment opportunities.

Final agreement on the Tunngavik Federation of Nunavut: Having received Royal Assent on 9 July 1993, the final agreement provides ownership to the Inuit of Nunavut of approximately 350 000 km^2 of land, 36 000 km^2 of which include mineral rights, financial compensation of $1.148 billion over 14 years, a share of resource royalties, guaranteed wildlife harvesting rights, and participation in decision-making processes that concern land and environmental management. A political accord that has been signed by the Tunngavik Federation of Nunavut, the Government of Canada, and the Government of the Northwest Territories will create, by the year 1999, a new territorial government of Nunavut in the eastern Arctic; in its powers and institutions, it will have a relationship with the federal government similar to the relationship that municipal governments have with the provinces.

Land claim agreement of the Sahtu Dene and Métis in the Northwest Territories: Having received Royal Assent on 23 June 1994, the agreement provides the Sahtu Dene and Métis with ownership of nearly 40 000 km^2 of land, 1 813 km^2 of which include subsurface rights, $75 million over 15 years, a continuing share of resource royalties, guaranteed wildlife harvesting rights, and participation in various decision-making bodies.

Specific claims

Launched 1 April 1991, the federal government's Specific Claims Initiative addresses cases of alleged nonfulfilment of Indian treaties or the alleged improper administration of lands or other assets under the *Indian Act* or other formal agreements. When a breach in lawful obligation can be demonstrated, allegations are researched and the claim settlements negotiated. Treaty land entitlement claims involve lands promised, but never actually granted, under a group of treaties that were signed with Indian bands, primarily in the Prairie provinces (Department of Indian Affairs and Northern Development 1993b). By the end of 1992, $208 million in claims had been settled — $169 million from the federal government and $39 million from the provinces (Department of Indian Affairs and Northern Development 1993c).

Environmental protection on Indian lands

As well as the areas covered by land claim agreements, Canada's 596 Indian bands have 2 261 reserves, covering approximately 27 110 km^2 — an area about half the size of Nova Scotia (Department of Indian Affairs and Northern Development 1990). Most Canadians benefit from a collection of regulations that deal with environmental problems such as solid waste disposal, industrial emissions, and water supply and treatment. Canadians living on reserves, however, are not afforded the same level of environmental protection. Provincial environmental statutes, regulations, and permits governing the use of land and activities on the land often have no legal force on Indian lands. This situation has created what many refer to as a "regulatory gap" in relation to matters such as disposing of waste, dealing with contaminated soil, licensing commercial operations (and imposing conditions in the licence that govern emissions and effluents), and responding to environmental emergencies such as spills, leaks, and explosions. This gap sometimes also applies to drinking water.

The review of CEPA currently under way includes studies of various means of protecting the environment on Indian lands more effectively (Environment Canada 1994b). In December 1995, the government proposed to amend CEPA to give the Minister of the Environment authority to enter into agreements with Aboriginal peoples to administer regulations on such issues as pollution prevention and control (Government of Canada 1995a).

Land use planning and management

Contemporary approaches to land use planning attempt to assess land use choices from a broadly based, comprehensive, and long-term perspective. This kind of approach calls for common goals and policies among governments and a structure and process that enable government agencies and the public to participate effectively in decision-making.

British Columbia, Saskatchewan, Manitoba, Ontario, Quebec, and Prince Edward Island have developed provincial land use policies and implementation strategies. In the Northwest Territories and Yukon, regional land use planning processes are being put in place through the implementation of Aboriginal land claim agreements.

Alberta, Quebec, New Brunswick, Prince Edward Island, and Newfoundland have legislation that provides for regional planning across municipal boundaries. (Alberta is reviewing its legislation, and the new *Municipal Government Act* will not have this provision.) Traditionally, the focus of such plans is on regional concerns such as industrial land use, open space, and infrastructure. Today, however, sustainability is becoming a focus. For example, regional planning in Quebec is being revised to incorporate sustainable development considerations.

Achieving sustainable land use

Background

Achieving sustainable land use implies planning to maintain a prosperous and diverse economy without compromising environmental integrity and the ability of the land to replenish renewable resources (e.g., maintaining the quality of the soil), while ensuring that the social fabric is preserved and enhanced.

A decade ago, the Royal Commission on the Economic Union and Development Prospects for Canada (1985), also known as the Macdonald Commission, assessed the condition of Canada's lands. Among other things, the Commission noted that agricultural lands were being lost to sub-

urbs and shopping centres. As well, the country's richest and most accessible mineral and hydrocarbon deposits were already in production. Lifestyles were based on rapid consumption of natural resources.

Although there is still much work to be done, over the past decade a number of approaches to attaining sustainable land use have been developed or furthered. *Our common future*, the report of the World Commission on Environment and Development (1987), presented the core ideas of sustainable development. Since its publication, sustainable development has become a central theme in land and resource planning, reflecting not so much a change of values as a new intensity of focus.

Provincial governments across the country began to review their land and resource planning systems, and most provinces undertook initiatives to increase the protection of representative ecosystems. For example, the Commission on Resources and Environment, established in 1992 by the province of British Columbia as an independent commission to help resolve valley-by-valley conflicts over land use, developed a land use charter that was subsequently adopted by the provincial government (Commission on Resources and Environment 1994). As well, the planning processes initiated by this commission resulted in land use plans that include lands for protection. The commission was terminated on 31 March 1996.

The Arctic Environmental Strategy remains one of the primary federal vehicles for promoting sustainable development in the Canadian Arctic. Its goal is to preserve and enhance the integrity, health, biodiversity, and productivity of Arctic ecosystems (see Chapter 9). On a national level, the concept of "ecosystem-based planning" became well-known through the publications of the Royal Commission on the Future of the Toronto Waterfront (e.g., 1992), or Crombie Commission. Essentially, it means land use planning that is based on natural boundaries and that respects the integrity of ecosystems (see Chapter 12).

Integrated land use planning and management

By examining all uses of land in an integrated manner, it is possible to link social and economic development with environmental protection and enhancement, make the most efficient trade-offs, and minimize conflicts. This integrated approach is based on relating sectoral planning and management activities to the capabilities and limitations of landscapes to support various land uses.

Many integrated land use planning and management efforts are under way at the provincial level, including strategies for wildlife, parks and protected areas, and forestry. For example, British Columbia, Alberta, Saskatchewan, and Ontario have structured approaches to land use planning. The approaches offer a framework that permits the inclusion of additional issues in the planning process. British Columbia's former Commission on Resources and Environment (CORE) had legal responsibility under the *CORE Act* (1992) to develop a province-wide strategy for land use and related resource and environmental management. Saskatchewan has adopted a forest management policy framework and is developing a new Forest Act, both of which require forest land use planning. Since 1991, the Quebec departments of Environment and Wildlife and of Natural Resources have conducted an experimental integrated forest resource management project covering forestry, wildlife, water, and land. The project aims to develop management and modelling tools and implement integration approaches on a trial basis. A user guide for integrated management of forested areas and an integrated management plan for a pilot area will be completed in 1996.

Ecosystem frameworks are increasingly being used in the assessment of current land use practices across Canada. For example, 10 large-scale environmental studies under Environment Canada's Eco-Research Program are focusing on a cross-disciplinary approach to resource management. These 10 studies are providing a series of models on which to develop, test, and recommend management options for achieving sustainable development.

Despite these signs of progress, responsibilities for land are sometimes fragmented and efforts are uncoordinated, with agencies having specific but very limited roles with respect to one or two dimensions of land use issues. Nevertheless, land is increasingly being managed in a manner designed to sustain the resource base.

Canada's protected natural areas

One component of sustainable development is the protection of ecosystems. An important goal for Canada, as unanimously endorsed by the House of Commons, is to protect, in its natural state, a representative sample of each of the country's natural regions, amounting to at least 12% of Canada. The federal government will work cooperatively with provincial and territorial governments, nongovernmental organizations, Aboriginal peoples, the private sector, and individual Canadians towards this goal. Part of the federal commitment to this goal is to complete the national parks system by the year 2000.

The World Conservation Union (IUCN, formerly the International Union for the Conservation of Nature and Natural Resources) has developed a classification system to facilitate the designation of environmentally significant areas with appropriate levels of protection. Box 14.4 (Chapter 14) outlines the current version of the IUCN categories of protected areas, including their defining characteristics and typical management practices. The present status of Canada's network of protected areas is summarized in maps that appear in Chapter 14. Progress made since the last State of the Environment Report for Canada was produced in 1991 (Government of Canada 1991c) is also documented in that chapter.

Although the number of protected areas has increased over the decades, pressures from resource development and other human activities are also increasing. Many protected areas in Canada are surrounded by logging and agricultural operations, mineral and hydrocarbon exploration and extraction activities, hydroelectric dams and related water impoundments, road networks, and recreation and tourism developments. However, such developments as roads and modifications to water-

ways, by opening up protected areas to tourism and recreation, may increase awareness of the importance of protected areas and help integrate them with the overall landscape. Table 10.9 shows the size of protected areas by jurisdiction for IUCN categories I–III and I–VI and the percentage of the total land and water area this represents.

Even high levels of protection cannot safeguard areas and all that they contain from declines in environmental quality, which are a result of a great many human activities taking place outside their boundaries. For example, protected areas are subject to long-range air and water transport of pollutants, such as pesticides and other chemical compounds, toxic metals, and acidic deposition; they are also subject to elevated UV-B levels owing to stratospheric ozone depletion and fluctuating water levels owing to dams.

Some protected areas also experience stress caused by activities taking place within their boundaries. Protected areas are increasingly affected by habitat fragmentation and alteration due to the effects of development, competition and disease from exotic or nonnative plant and animal species, and pressures from tourism and recreational facilities (see Chapter 11).

Current Canadian priorities

Agenda 21 is a blueprint for sustainable development that has been adopted by most countries, including Canada. It arose out of the United Nations Conference on Environment and Development — the Earth Summit — which was held in Rio de Janeiro in 1992. Chapter 10 of *Agenda 21* presents an integrated approach to land planning and management (UNCED 1992). Based on this chapter, Canada has identified the following domestic land-related priorities:

1. Emphasize provincial functions: except for federally controlled lands, the provinces have constitutional authority over laws and policies related to land use.

2. Increase the use of information systems, including geographic information systems:

   • assess systems for environmental, economic, and social data related to land

Table 10.9

Protected areas by jurisdiction

Jurisdiction	Nfld.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	Y.T.	N.W.T.	Canada
	Area (km²)												
IUCN categories I–III													
Federal	2 342	26	1 354	445	5 504	2 188	2 978	4 295	63 036	7 442	14 568	101 086	205 264
Private landowner	0	0	0	0	11	0	0	0	0	0	0	0	11
Provincial/territorial	4 375	19	94	226	4 642	49 835	10 816	11 113	2 202	58 952	0	115	142 389
Other[a]	0	0	0	0	0	80	13 226	176	0	2 334	0	0	15 816
Total	6 718	45	1 448	671	10 157	52 103	27 020	15 584	65 237	68 728	14 568	101 201	363 479
IUCN categories I–VI													
Federal	2 353	27	1 415	508	6 527	2 413	2 979	5 136	63 180	7 483	40 422	212 378	344 820
Private landowner	0	0	0	0	11	0	0	0	0	0	0	0	11
Provincial/territorial	5 005	51	1 485	3 449	151 509	50 088	46 046	11 788	3 338	59 372	9 030	4 542	345 702
Various/multiple[b]	0	0	0	0	0	772	0	88	0	3	0	26 464	27 327
Other[a]	0	0	287	0	3	9 375	14 913	11 547	0	2 334	0	0	38 459
Total	7 358	78	3 187	3 957	158 050	62 648	63 938	28 558	66 518	69 191	49 452	243 384	756 319
	% of total area												
IUCN categories I–III													
Federal	0.58	0.46	2.44	0.61	0.36	0.20	0.46	0.66	9.53	0.79	3.01	2.95	2.06
Private landowner	0	0	0	0	0	0	0	0	0	0	0	0	0
Provincial/territorial	1.08	0.33	0.17	0.31	0.30	4.66	1.66	1.70	0.33	6.22	0	0	1.43
Other[a]	0	0	0	0	0	0.01	2.03	0.03	0	0.25	0	0	0.16
Total	1.66	0.79	2.61	0.91	0.66	4.88	4.16	2.39	9.87	7.25	3.01	2.95	3.65
IUCN categories I–VI													
Federal	0.58	0.48	2.55	0.69	0.42	0.23	0.46	0.79	9.56	0.79	8.36	6.20	3.46
Private landowner	0	0	0	0	0	0	0	0	0	0	0	0	0
Provincial/territorial	1.23	0.90	2.68	4.70	9.83	4.67	7.08	1.81	0.50	6.26	1.87	0.13	3.47
Various/multiple[b]	0	0	0	0	0	0.07	0	0.01	0	0	0	0.77	0.27
Other[a]	0	0	0.52	0	0	0.88	2.29	1.77	0	0.25	0	0	0.39
Total	1.81	1.38	5.74	[illegible]	10.26	5.86	9.84	4.38	10.06	7.30	10.23	7.10	7.59

[a] Other levels of government.

[b] Joint management (e.g., federal/provincial/territorial/private).

Source: National Conservation Areas Database, State of the Environment Directorate, Environment Canada

resources and for land capability and land use and management patterns;

- improve coordination among existing systems of sectoral land resource data and strengthen the national capacity to gather and assess data (conservation data centres exist in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, and Quebec);
- provide the appropriate technical information necessary for informed decision-making on land use and management in accessible forms to all sectors of the population; and
- develop indicators of sustainability for land resources, taking into account environmental, economic, and social factors.

3. Strengthen federal–provincial–territorial relations through the various ministerial harmonization councils that aim to eliminate overlap and duplication with respect to natural resource issues. Such councils address, for example, environment, agriculture, forestry, energy, mining, and protected areas.
4. Consult through such mechanisms as round tables (federal, provincial/territorial, and local) and multistakeholder partnerships of government, Aboriginal groups, business, and nongovernmental organizations.
5. Support Aboriginal land use initiatives (e.g., according to Article 10: c, Protecting Traditional Practices, of the United Nations Framework Convention on Biological Diversity).
6. Coordinate state of the environment reporting at national, provincial/territorial, and local levels to provide information that Canadians need to make more environmentally responsible decisions. The Canadian Council of Ministers of the Environment is establishing a set of reporting guidelines.
7. Develop and apply an ecosystem approach to land use planning and management through the application of both national ecozone and continental ecosystem frameworks.

Canadian initiatives towards sustainability of land

Two recent national initiatives to advance environmentally sound land use planning are of note. The Federal/Provincial Committee on Land Use has launched a program called the Perspective on Land Issues in Canada Process to identify:

- the major land issues that the country will face over the next decade;
- broad options for resolving the issues; and
- the role that land use planning plays and should play in the implementation of sustainable development.

The committee held a national forum during the summer of 1995 and is seeking input from various sectors of Canadian society. As well as the need to strengthen coordination among existing sectoral land resource data systems, there is a need to enhance the capacity to gather and assess data at the national level and to formulate complementary and mutually supportive policies at different jurisdictional levels. By addressing these and other needs, the program is expected to help set the stage for still more progress towards the goals of Chapter 10 of *Agenda 21*, as outlined above.

The second notable initiative is being undertaken by Statistics Canada. The agency is developing a set of Land Accounts as part of the environmental accounting under the Canadian System of National Accounts. These accounts will present integrated land use, cover, capability, and value statistics. Land cover data are being linked with socioeconomic information from the censuses of agriculture and population.

These undertakings and the numerous other initiatives in support of sustainable land use being conducted throughout Canada by all orders of government — federal, provincial, territorial, regional, and municipal — should bear fruit in the balance of this decade and into the next century.

FRESH WATER

Canada's fresh water in perspective

Compared with all the water on Earth, the amount of available fresh water is very small. More than 97% of the Earth's water is saline, found in the oceans and seas; 69% of the rest is in the form of perennial snow and ice, such as glaciers and ice caps (World Resources Institute 1994). The remaining water, in the atmosphere, lakes, rivers and streams, wetlands, and the ground, amounts to less than 1% of the total.

Lakes, rivers, and wetlands: only scratching the surface

Lakes and rivers cover about 755 180 km^2 of Canada's surface area (Energy, Mines and Resources Canada 1989). Canada's rivers discharge about 9% of the world's renewable water supply. Some 60% of this runoff flows into the Arctic Ocean and Hudson Bay; the rest drains to the Pacific Ocean and Atlantic Ocean basins, with a minor flow to the Gulf of Mexico (Fig. 10.14).

Wetlands are singularly productive freshwater areas (see Box 10.1). Wetlands are typically linked to groundwater: those located on higher ground (e.g., many prairie sloughs and potholes) function as important groundwater recharge areas, whereas those in low-lying areas may receive most of their water from groundwater. Wildlife dependent on wetlands may thus be affected by contaminated groundwater sources (Eaton et al. 1994).

Groundwater: out of sight, out of mind?

Most of the water returning to the land as precipitation penetrates into the soil's surface layers. Much of this water is retained by the soil and is returned to the atmosphere by evaporation from the soil and transpiration from vegetation. Some water, however, percolates deeper and enters the *saturated zone* (the entire region below the water table). Eventually — sometimes over thousands of years — this groundwater discharges again to the soil and is then absorbed and transpired by vegetation or discharged to streams, lakes, or oceans.

Although unseen, groundwater is an essential link in the hydrologic cycle, in some plant growth, and in the formation of many ecosystems. Much of the water in rivers and lakes has passed through the groundwater zone before entering surface water, usually as very shallow (near-surface) flow to small watercourses; these, in turn, feed the larger streams (Bras 1990). Apart from during snowmelt and heavy rains, it is groundwater that maintains the flow of most streams and the water level of lakes and sustains many wetlands. Springs, a form of groundwater discharge, provide habitat, refuge, and drinking water for wildlife in dry areas. The soil and the aquifer (zone saturated with groundwater) below also perform important filtering and buffering functions, such as neutralizing acid rain (see "Acidic deposition" later in this section).

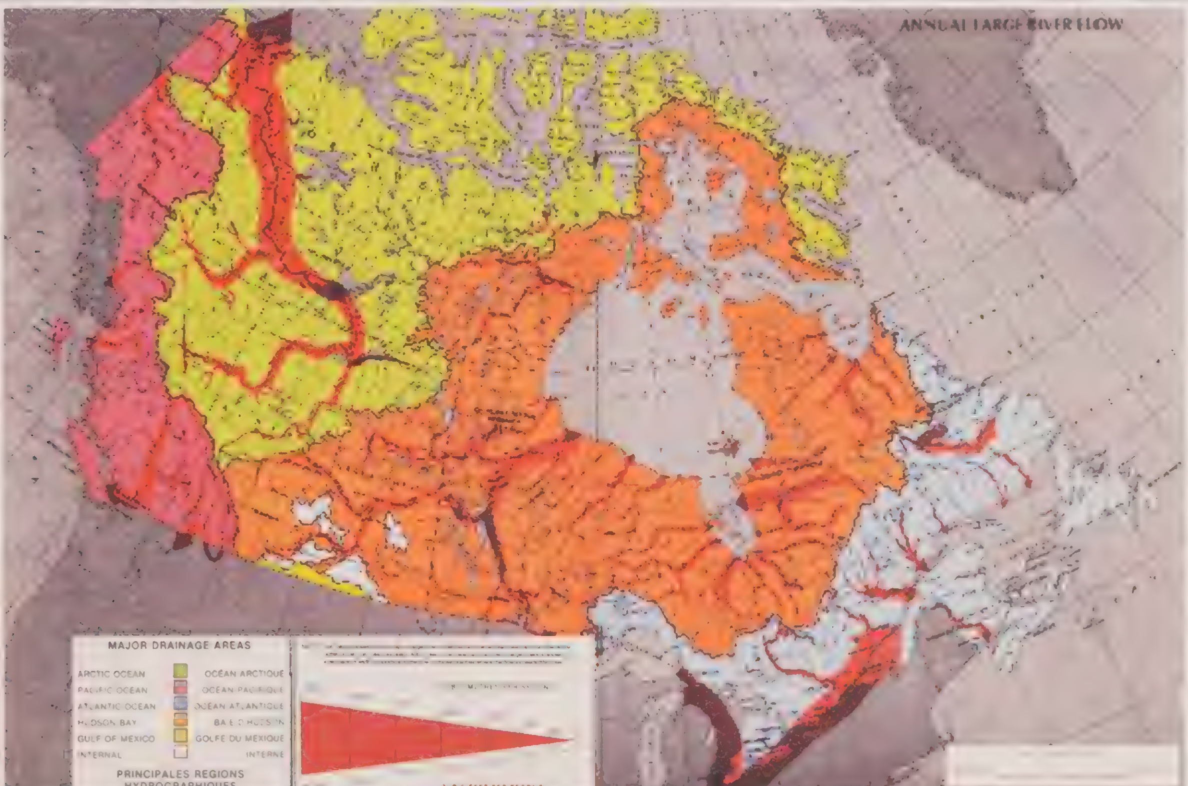
Making the links: the hydrologic cycle

Driven by the sun, the hydrologic or water cycle converts solar energy into energy that performs the main transport functions in ecosystems. Water cycles throughout the oceans, the atmosphere, the soil, bodies of fresh surface water, and living organisms. The main processes, illustrated in Figure 10.15, are evaporation, precipitation and condensation, infiltration to soil and groundwater, flow to vegetation or to streams and other water bodies, and then either transpiration from plants into the air or runoff via rivers to the oceans. These processes purify the Earth's supply of water, reshape the Earth itself by erosion, drive other biogeochemical cycles, and redistribute the elements necessary for life (e.g., nutrients and carbon). The hydrologic cycle is a key part of the global climate system and provides the condition and basis for all life.

The importance of water and the hydrologic cycle to humans

Like all living organisms, humans depend on water and the hydrologic cycle: 83% of the human circulatory system is water; drinking, respiration, perspiration, and elimination of wastes are all part of this cycle. But society's dependence on water goes much further. Large amounts of water are needed for most economic activities: agriculture and mining, food processing, manufacturing (e.g., about 120 000 L of

Figure 10.14
Streamflow and drainage basins in Canada



water are used in the production of an average automobile), and, most of all (over 60% of all withdrawal), in the generation of electricity from thermal power plants. The impacts of these changes (ultimately on the water cycle) vary in intensity: in agricultural irrigation, a large percentage of the water returns to the atmosphere through evapotranspiration; water used for other applications returns to its source but contains waste products (or has to be treated to remove them); water used for thermal power plants contains waste heat on its return; water used to drive turbines for hydroelectricity is temporarily removed from its course.

Lakes and rivers provide towns and cities with a convenient means of discharging wastes. Many industries also rely on fresh water for waste disposal, and the combined burden on these waters has often led to their degradation, for the most part within a historically brief period of time. Waterways also facilitate transportation and are valued for recreational activities. As a final example of the importance of water to humans, Aboriginal people and others view the rivers and large lakes of this country as an integral part of their own identity.

The following sections briefly discuss some of the chemical, physical, and biological effects of human activities on Canada's fresh water.

Box 10.1
Wetlands: productive, purifying, and precious

Wetlands cover about 14% of Canada's land surface (see the "Land" section of this chapter). Among their ecological and socioeconomic functions, wetlands:

- *supply food and other essential life needs for many species of shorebirds, waterfowl, fur-bearing mammals, fish, and shellfish;*
- *provide products of use to people, including food (wild rice, cranberries, fish, and wildfowl), energy (peat, wood, and charcoal), and building materials (lumber);*
- *provide recreational areas for activities such as hunting, fishing, and birdwatching;*
- *filter sediments and toxic substances;*
- *aid in the breakdown of harmful contaminants into nutrients that can be taken up by living organisms, and neutralize disease-causing pathogens; and*
- *absorb some of the impact of hydraulic events, such as large waves and floods.*

It used to be common practice to drain wetlands or fill them in. In many parts of southern Canada, more than two-thirds of the original wetlands have been lost. Today, however, the importance of wetlands is better appreciated. As one indication of this, wetlands are the only type of ecosystem designated for conservation by an international convention — the Ramsar Convention (see Chapter 14). As well, degraded or lost wetlands are now being restored, reversing the former trend. Wetlands are even being created in places where they did not formerly exist, as a means of treating municipal sewage — over 500 such wetlands have been "constructed" in the United States alone (Wood 1994).

Atmosphere-related effects on the state of fresh water

Acidic deposition

Acidic deposition of sulphate and nitrate (from sulphur dioxide and nitrogen oxides in the air; see the "Atmosphere" section of this chapter) continues to be one of the most severe stresses on freshwater ecosystems in eastern Canada. The Canadian Shield region of eastern Canada and parts of the Appalachians or Atlantic Maritime ecozone, with their thin soils and granitic bedrock, have little natural buffering capacity for neutralizing these acids. The southern Shield, the St. Lawrence lowlands, the Appalachian region, and much of the Atlantic Maritime ecozone have also been exposed to acidic deposition from smelters in northern Manitoba, Ontario, and Quebec and from thermal generating stations in the United States, Ontario, New Brunswick, and Nova Scotia. The area at risk (the southern Shield, southern Nova Scotia and New Brunswick, and much of Newfoundland) contains over 700 000 lakes (Clair et al. 1995).

Models of water chemistry have predicted that 4.3% (approximately 20 000) of the vulnerable lakes in this region would become acidic (pH under 5) under 1980 levels of emissions (Jones et al. 1990). This would be reduced to 3% if Canada alone reduced emissions by the agreed-upon limits (see the "Atmosphere" section of this chapter) and to 1.9% (or 8 500–8 800 lakes) if both Canada and the United States did so (Jones et al. 1990; Committee on Lake Acidification 1992). An up-to-date federal–provincial assessment of the impact of acidic deposition on freshwater systems is due in 1997 (National Air Issues Coordinating Committee 1994). Work in progress for this assessment is described by Lam et al. (1995). The new assessment will include consideration of the biological as well as the chemical impacts. However, it is already clear that many lakes are likely to continue to lose populations of fish and other freshwater species. Assessments of progress in limiting emissions are carried out through the 1991 Canada–U.S. Air Quality Agreement (Canada–United States Air Quality Committee 1994).

Acid rain has caused considerable damage to fish populations in rivers in southwestern Nova Scotia. Here, loss or depletion of salmon populations due to acidification has occurred in 31 rivers. Thus, one-third of the available Atlantic Salmon habitat in Nova Scotia has been lost since the 1950s (Watt 1986, and personal communication).

As noted in the "Atmosphere" section of this chapter, considerable reductions in sulphur dioxide emissions have taken place in Canada and the United States since the 1980s, but less progress has been made in reducing nitrogen oxide

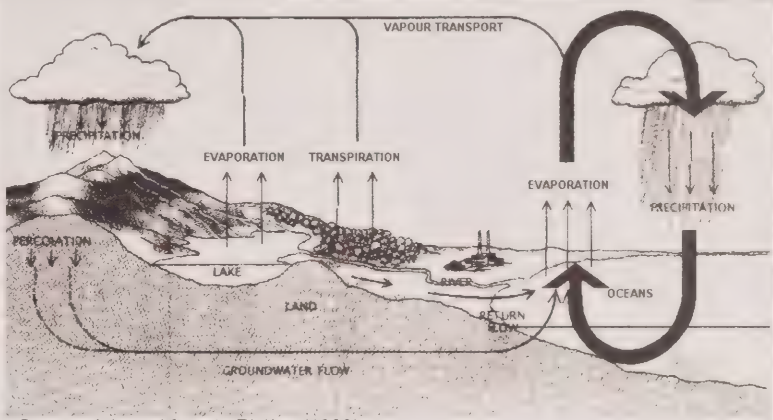
emissions. To date, the results for the restoration of freshwater ecosystems have been mixed.

For example, monitoring and research in the Sudbury region of Ontario showed that some lakes that have been severely affected by acidification partially recovered as their exposure to acidic deposits was reduced (Gunn and Keller 1990; Keller and Yan 1991; Keller et al. 1992). Sulphur dioxide emissions from the nickel smelters had caused some of the most severe lake acidification in Canada and had resulted in extensive damage to fish and other biological communities. However, when sulphur dioxide emissions were significantly lowered in the 1970s and early 1980s, chemical water quality of some lakes improved rapidly and was sometimes accompanied by substantial biological improvements. Algae, phytoplankton, zooplankton, benthic invertebrates, and other species low in food webs showed some recovery, even in severely stressed lakes. However, although many lakes are recovering, numerous others in the Sudbury area remain acidic. Water in some lakes, particularly those with poor acid-neutralizing capacity, even became more acidic over the 1983–1991 period (McNicol and Mallory 1994).

Meanwhile, long-term monitoring of 202 lakes in southeastern Canada between 1981 and 1994 showed that 33% were improving, 56% were stable, and 11% were acidifying (Environment Canada 1996a; see Fig. 10.16).

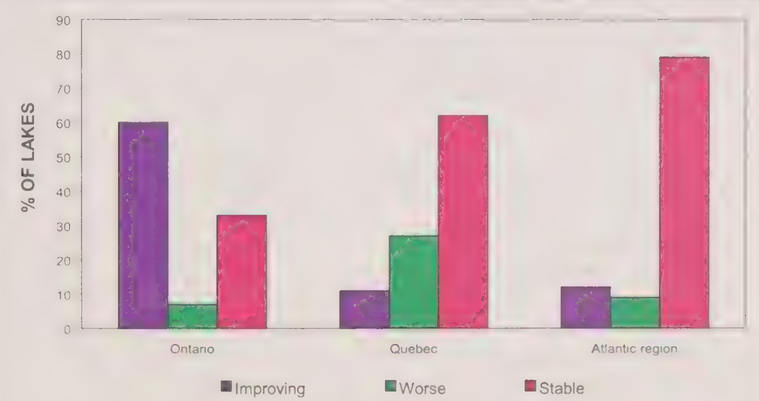
Thus, the effects of the reductions in sulphur dioxide emissions are not yet clear, and it will be some years before it will be known whether they have had the hoped-for result. Drainage basins and their lakes may need years to reach a higher pH equilibrium corresponding to lower acidic deposition. Responses also vary by region and depend on landscape type, soils, and other regional factors. Another interesting finding from the reported data is the appearance of increasing nitrate concentrations from nitrogen oxide deposition in Quebec watersheds. Until now, the primary acidifying agent in North American lakes has been sulphate.

Figure 10.15
The hydrologic cycle



Source: Adapted from la Rivière (1989).

Figure 10.16
Trends in lake acidity by region, 1981–1994



Source: Environment Canada (1996a).

In Atlantic Canada, the soils have little capacity to buffer acidity, and, as a result, recovery has been disappointingly slow. Over 142 000 water bodies in the region are considered sensitive to acid stress (Government of Canada 1991c). Sulphate deposition has declined to an average of 10–15 kg/ha per year from a high of 40 kg/ha per year or more, with the result that some lakes and rivers appear to be recovering; however, deposition is still too high for the more acid-sensitive lakes and rivers, particularly in southern Quebec, southwest Nova Scotia, and southern New Brunswick. A critical load value of less than 8 kg/ha per year is probably necessary to protect sensitive freshwater ecosystems in Atlantic Canada (RMCC 1990; Jeffries and Lam 1993). Because current sulphur dioxide reduction programs in Canada and the United States are based on the objective of 20 kg/ha per year, as many

as one-quarter of Atlantic Canada's lakes likely will not recover, even with full implementation of these programs (Eaton et al. 1994).

Airborne contaminants of continental and global origin

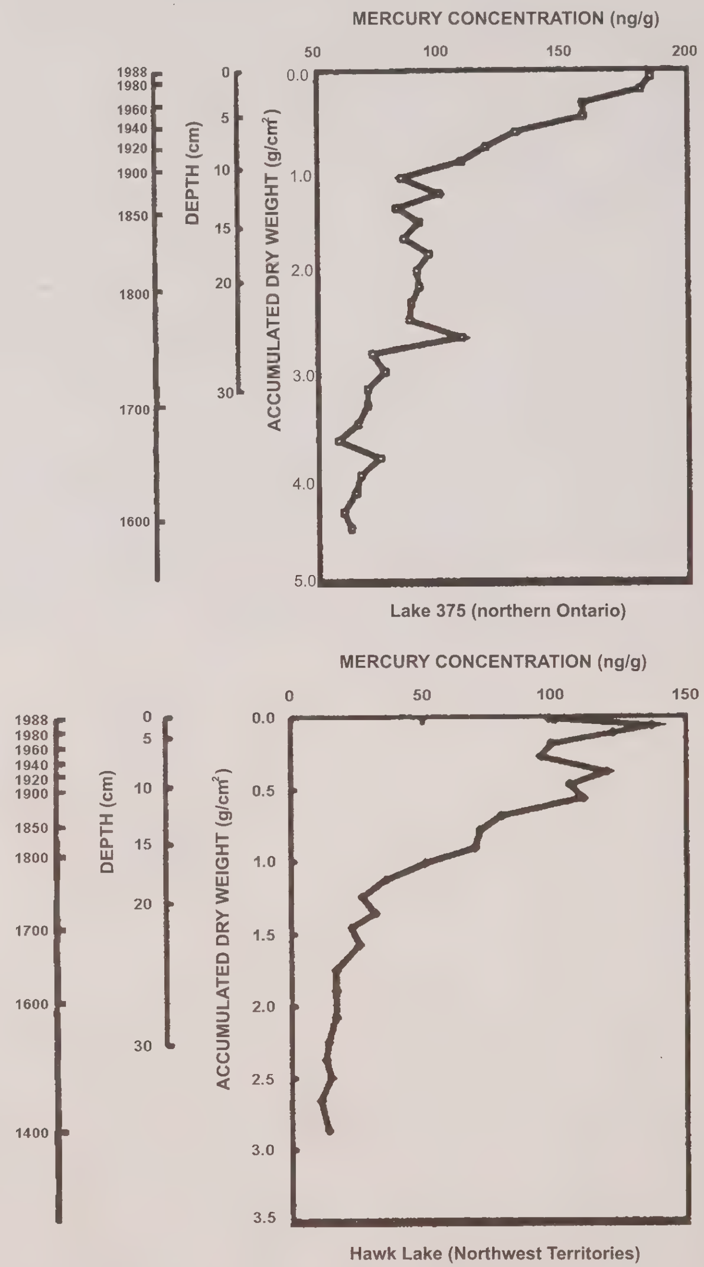
The acidification of remote, seemingly pristine lakes from sources far away is one reason why the issue of acid rain gripped the attention of so many Canadians in the 1980s. Now, numerous contaminants (e.g., PCBs and other organochlorines, PAHs, radionuclides, mercury, lead, and cadmium) have been found in lakes in the high Arctic where there is no known local anthropogenic source (Lockhart et al. 1992, 1993; Hermanson 1993; Schindler 1994; Muir et al. 1995).

Organochlorine contamination of Arctic lakes and rivers appears to be widespread; PCBs and a large number of other organochlorines have been found there (Muir et al. 1995). Mercury contamination in northern lakes and rivers also appears to be increasing; sediment cores (indicators of past concentrations) show steep increases since the beginning of this century (see Fig. 10.17).

It appears that these contaminants originate from all industrial regions of the northern hemisphere and are distributed by air currents (see Chapter 9). In the Canadian Arctic, atmospheric inputs of mercury, among other contaminants, have increased by a factor of three since 1900 (G. Koshinsky, Freshwater Institute, Department of Fisheries and Oceans, personal communication; see also Lockhart et al. 1995 and Chapter 9). In the Great Lakes region, most of certain contaminants found in Lake Superior come from long-range air transport (see Chapter 6). A recent analysis (Cohen et al. 1995) showed that practically all sources in Canada and the United States contribute to such contamination, but that only 40–60% of the contaminants from these sources are deposited within continental North America; the rest are dispersed into the oceans and around the globe.

Water bodies collect contaminants deposited within their drainage basin, and aquatic

Figure 10.17
Mercury in sediment slices from two northern lakes



Note: Dates earlier than 1850 are extrapolations.
Source: Lockhart et al. (1993).

biota in the water bodies bioaccumulate them. In general, the organochlorine found at highest concentration in Arctic fresh waters is α-hexachlorocyclohexane (HCH), whereas toxaphene, PCBs, and chlordane are the compounds found at highest concentrations in fish (Lockhart et al. 1992). Mercury concentrations in some larger, older fish in the eastern Arctic frequently exceed guidelines for mercury in commercial fish (Hermanson 1993; W.L. Lockhart, Freshwater Institute, Department of Fisheries and Oceans, personal communication). PCBs have also found their way into the breast milk of Aboriginal women in the Arctic (see Chapter 9).

Climate change

Global temperatures are expected to increase as a result of human-caused changes in concentrations of greenhouse gases (see discussions in Chapter 15 and the "Atmosphere" section of this chapter). Rises in temperature could have a large effect on the hydrologic cycle and the distribution of water. The most important impacts (Environment Canada 1992) could be the following:

- less water would be stored as snow in the winter;
- there would be earlier runoff from snowmelt;
- less water would be stored in glaciers (resulting in smaller glaciers and polar ice caps);
- permafrost would retreat;
- the prairies would probably be drier;
- coastal flooding would be likely; and
- freshwater–seawater boundaries would shift (resulting in saltwater intrusion in groundwater wells).

Some models also indicate that extreme natural events (heavy rains, droughts, etc.) may become more frequent. In turn, these changes in the hydrologic cycle would affect wetlands and other aquatic ecosystems, plant growth in terrestrial ecosystems, and so on, as well as agricultural productivity, water supplies, navigation, and other human activities.

The most reliable general circulation models, or GCMs (see Chapter 15), show the greatest warming occurring at high northern latitudes; they also tend to show an area cooling northeast of the Labrador coast and small temperature changes in extreme eastern Canada. However, these global models have insufficient resolution to model the regional characteristics of climate with much confidence, and it is these regional characteristics that have the most influence on natural hydrologic systems and human activities. Pending development of more reliable regional atmospheric models, hydrologic models explore the different regional possibilities or scenarios for the water regime consistent with projections of global models. The regional scenarios differ in detail, but they all paint a picture of possible significant changes in the water regime under climate change. A few important aspects of these regional scenarios (Environment Canada 1992) are listed below (for more detail, see Chapter 15 and the relevant regional chapters):

- *All coastal areas*: rise in sea level, altering the productive ecosystems of estuaries and coastal wetlands; shifts in the freshwater–saltwater boundaries near the mouths of rivers, affecting aquatic ecosystems and water supplies; saltwater intrusion in aquifers and water wells; warming of rivers, with potential impacts on migration and spawning of salmon and other fish.
- *Prairie provinces*: more frequent and prolonged droughts, with increased drying up of wetlands; increased frequency of extreme events (e.g., flash floods).
- *Great Lakes–St. Lawrence River basins*: decreased runoff by 8–25%; drop in levels of the Great Lakes by 0.5–2.5 m (depending on lake and scenario); reduced ice cover; decrease in soil moisture by 14–67% (depending on region and scenario); decrease in flow and water levels in the St. Lawrence, leading to increased tidal effects and saltwater intrusion in the lower river (Mortsch et al. 1995).
- *Arctic and taiga*: likely retreat northward of the region of intermittent (discontinuous) permafrost, particularly in the northwestern portion, with adverse effects on buildings, pipelines, and roads as the permafrost melts.

The biological and physical impacts of climate change can also be estimated by long-term monitoring of the behaviour of aquatic ecosystems under climatic variability, such as that carried out by Schindler et al. (1990).

The specific regional impacts of climate warming are uncertain, but there is a considerable degree of consensus that major changes (corresponding to some aspects of some scenarios) will occur. Some natural ecosystems (e.g., in small lakes) could change significantly. In an uncertain situation, flexibility of response is essential. Examples of the measures that can be taken to improve society's capacity to respond to changes in the water regime are listed in Table 10.10 (for a more general discussion, see Chapter 15). However, in cases where these measures involve building new structures, such as dams, they may actually damage the ability of ecosystems to respond to climate change — for example, by interfering with wildlife migration to new habitat.

Ultraviolet radiation

Depletion of ozone in the stratosphere has already increased the amount of ultraviolet radiation reaching the Earth (see Chapter 15 and the "Atmosphere" section of this chapter), and this amount is expected to increase further before it levels off. Ecological effects on freshwater systems and related socioeconomic effects may be serious, widespread, long lasting, and difficult to reverse.

Effects on aquatic ecosystems are expected to be concentrated in shallow (less than 1 m) waters, such as wetlands, estuaries, and shore areas. These are precisely the areas of highest productivity, which are critical for the early development and the food sources of many species (Steadman and Regier 1987; Bukata et al. 1995; Scully and Lean 1995). Biota in clear waters are more at risk than those in the brown-water lakes and streams of northern Canada; the reason for this is that brown water contains more dissolved organic carbon.

which absorbs some ultraviolet radiation, thereby reducing the levels penetrating to greater depths.

Hatching success of amphibians is directly related to UV-B exposure, providing a possible, if partial, explanation for the marked decrease in amphibian populations (and species diversity) reported around the world (Blaustein et al. 1994; Blaustein and Wake 1995). The early life stages of fishes are also sensitive to UV-B exposure (Hunter et al. 1982); recent evidence suggests that the DNA (deoxyribonucleic acid — the molecular basis of heredity in most organisms) of cod larvae can be damaged by UV-B radiation to depths of 20 m in clear water columns (Vetter and Kurtzman 1994; Vetter 1996). Another disturbing finding is the special sensitivity of "grazers" (e.g., chironomids, a type of midge) to UV-B radiation (Bothwell et al. 1994). In shallow experimental streams, UV-B exposure kills off the majority of these grazers. The algae upon which these grazers feed, no longer heavily exploited, increase in biomass, despite also being negatively affected by the UV-B exposure. As these grazers are a source of food for organisms higher in the food web (e.g., fish and lower vertebrates), the results of Bothwell et al. (1994) underscore potentially important indirect effects of UV-B radiation. Significant alterations in aquatic ecosystems, resulting from UV-B radiation and other forces of global atmospheric change, have been observed in the areas of the world where UV-B levels have increased significantly (Schindler et al. 1996; D. Lean, National Water Research Institute, Environment Canada, personal communication).

Water withdrawal and use by Canadians

Although Canada as a whole has abundant water supplies, physical limits on the available water are a serious issue in certain areas. On the prairies and in parts of the B.C. interior, which are dry in the summer, intensive irrigation competes with other uses for scarce water. Limits on withdrawals can also be a local issue when municipalities (e.g., Kitchener–Waterloo, Ontario) depend on groundwater and the available water depends on the annual recharge (see the discussion on groundwater in this section). In other regions of the country, the main impact of high water use is the stress on municipal infrastructure for water provision, distribution, and disposal; this may be called "functional" water scarcity. Discharge of used water is also one of the prime origins of water contamination.

Figure 10.18 provides a breakdown of water use in Canada. Canadians withdrew 45 billion cubic metres of water in 1991 — 88% more than in 1972. This corresponds to 4 500 L of water withdrawn per person per day for all uses and to 340 L per person per day for residential use. Such consumption is second only to that of the United States and is about twice as high as in an average European country. Although Canada has abundant water supplies, such high consumption creates excessive costs in municipal infrastructure, and the large amount of wastewater contributes to water pollution (Tate 1987, and personal communication).

A more detailed analysis shows that total withdrawal per person increased by 49% between 1972 and 1986 but remained practically constant between 1986 and 1991; residential use per person increased by 7% between 1983 and 1991 (Environment Canada 1994c). The data also show that the increase in withdrawal since 1986 is primarily due to the increased use of water for cooling in thermal power plants (over 60% of all withdrawal). Without that use, there would even have been a slight decrease, because significantly less water was used in manufacturing and mining. With the decreased likelihood of new megaprojects being started (see discussion of dams and diversions in this section), the same trend may be expected for water use by thermal power plants, albeit with a longer time lag.

Table 10.10
Adapting to climate change — options for responding to changes in hydrologic conditions

In aquatic ecosystems	• preserve and protect alternative areas of habitat and limit their physical modification (e.g., shorelines); • preserve migration corridors (escape routes); and • limit other stresses that may exacerbate climate impacts.
In drylands	• choose appropriate crops; • irrigate more efficiently; • design new criteria for adjustable water storage structures; and • promote the recharge of aquifers.
In flood-prone areas	• continue to prohibit development in floodplains; • continue to improve forecasting and warning systems and evacuation and relief plans; • improve present flood control structures; and • design new structures to handle more frequent extreme events.
On the coasts	• consider building barriers to erosion and saltwater intrusion; and • consider desalinization technologies.
In navigable waterways	• dredge shallows; • lighten barge loads; and • use other means of transport in times of low water levels.
Everywhere	• conserve water and energy; • repair leaky systems; • plan for strength and flexibility in new structures; • regulate land use to avoid building on areas prone to flooding; • establish water metering and realistic pricing; and • include water-efficient technology in building codes.

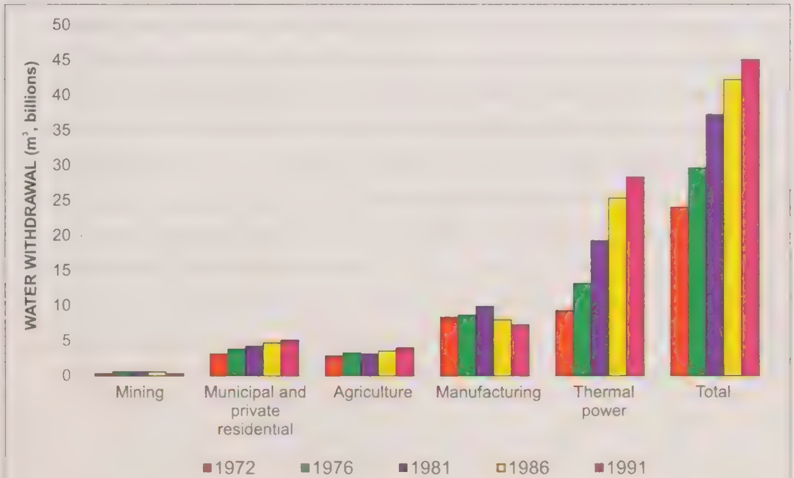
Source: Adapted from Environment Canada (1992); Regier (1993); Koonce and Hobbs (1994).

The final impacts of a restructured economy on industrial water use are not clear yet. Economic pressures will likely force industry into reduced water use and increased conservation, provided the true costs of water use are appropriately internalized (accounted for in the price of the water). This leaves agriculture (primarily irrigation) and municipal supply as the main water users that are increasing withdrawals without fully internalized costs for provision, distribution, and disposal.

In the agricultural sector, data for areas irrigated and water use differ depending on the methods and sources used. Data from the Prairie Provinces Water Board (R. Kellow, Prairie Provinces Water Board, personal communication) for irrigation in the Saskatchewan–Nelson basin (a major irrigation area) between 1951 and 1991 may be indicative of the general trend in agricultural irrigation. The area irrigated in this basin increased fivefold between 1951 and 1986 — to 624 000 ha — but remained practically constant over the next five years (2% increase by 1991). The amount of water applied per hectare, on the other hand, has not decreased since at least 1981 (about 4 300 m^3/ha net use for district irrigation and somewhat less for private irrigation).

The main issues in agricultural irrigation are the most appropriate apportionment of water among competing users in water-short regions and the true benefit–cost ratio of the food so produced. The overriding issue in municipal water use, on the other hand, is the cost of building and maintaining the municipal infrastructure. As the Inquiry on Federal Water Policy (Pearse et al. 1985) pointed out, major costs for the renewal and improvement of municipal infrastructure are imminent for most Canadian cities. Appropriate water pricing is recognized as the most effective method to evaluate the costs and benefits of water conservation in relation to engineering investments (Environment Canada 1987; Tate 1987). Under present conditions, conservation measures to reduce municipal water demands have been estimated to have a benefit–cost ratio of 15:1 when compared with the cost of expanded municipal infrastructure (D. Tate, Environment Canada, personal communication).

Figure 10.18
Total water withdrawal in Canada, 1972–1991



Note: For municipal and private residential uses: (a) private residential uses are estimates only; and (b) water supplied to industries from municipal water supplies is excluded.

Source: Data derived from National Water Use Database and Municipal Use Database (MUD), Water and Habitat Conservation Branch, Environment Canada.

Groundwater use is not shown explicitly in Figure 10.18 (it is integrated mainly into municipal use), but groundwater is an important part of the water used by Canadians. Over six million Canadians rely on groundwater for their water supplies, mostly in rural areas and small towns, and groundwater is used extensively for livestock watering and for industry (Hess 1986).

Trends towards increased water efficiency

For the economic reasons outlined above, municipalities as well as agricultural producers are moving towards increased efficiency in water use and closer to full-cost accounting. There is, in fact, great potential for more efficient water use. It has been estimated that with modern methods and technologies, farmers could cut irrigation water needs by up to 10% for extensive grain and oilseed production and by up to 50% for intensive fruit and vegetable production; industries could cut use by 40–50%, and cities by a third, all with no sacrifice of economic output or quality of life (H. Foerstel, Environment Canada, personal communication). The tools to work towards this goal are more efficient water technologies, stricter building and plumbing codes, structural improvements (metering, retrofitting, leakage repair, etc.), and public education. The driving force, however, will be price structures that reflect the full costs for supplying water and treating effluent.

A beginning has been made: in June 1994, the Canadian Council of Ministers of the Environment adopted a National Action Plan to Encourage Municipal Water Use Efficiency. It calls for federal and provincial governments to demonstrate water efficiency in their own operations, to harmonize provincial plumbing codes, and to develop a public education strategy. A second part of the plan calls for economic measures to encourage water efficiency at the municipal level.

Some municipalities are promoting water conservation through metering, price reforms, and public education campaigns. Moncton, New Brunswick, for one, has been installing meters that enable digital

transmission of information over existing telephone lines as a means to bill on the basis of volume used. However, most municipal water rate structures did not reflect a change in attitude as of 1991. A flat-rate structure (fixed price, independent of the amount of water used) was still the most common pricing method (see Fig. 10.19).

Water pollution

Water quality in Canada, compared with that in most countries, remains relatively high (Statistics Canada 1994a). Water pollution problems do exist in many parts of the country, however, usually in association with industrial, agricultural, or mining activities or human sewage. Small lakes and rivers in every province and territory, as well as large water bodies such as the lower Great Lakes–St. Lawrence system (see Chapter 6), have been affected by human activities. Groundwater contamination is also recognized as a widespread and growing concern.

Despite many regional and local studies of water quality in Canada, no comprehensive national study has been undertaken. In 1990, Health Canada conducted a limited survey of water treatment facilities. Municipal water supplies of 39% of the population were tested for a limited number of substances. Table 10.11 illustrates some of the survey results.

Surface waters: waste discharges and wastewater treatment

Rivers and lakes have long provided communities with a convenient means of disposing of sewage, industrial effluents, and other wastes. However, depending on the level of treatment provided, waste discharges may contain nutrients that lead to eutrophication or pathogens or toxic chemicals that make the water unfit for recreation and certain other uses. Only advanced treatment will remove toxic industrial by-products.

In general, the level of municipal wastewater treatment in Canada has been rising steadily (see Chapter 12). In 1983, 18.2 million people, three-quarters of the total population, were served by sewage systems, and 13 million of these were also served by some form of sewage treatment; the wastewater of the remainder was discharged untreated (see Chapter 12, Fig. 12.13). By 1991, the number served by sewers had risen to 20.5 million, nearly 80% of the population. Of these, 17.5 million were also served by some form of treatment. During this period, the numbers served by tertiary treatment rose from 5 million to 7.5 million, 37% of the population served by sewers. The most notable progress has been made in Quebec, where the population served by sewage treatment facilities increased from 12% to 56% between 1983 and 1991 (Environment Canada 1994c).

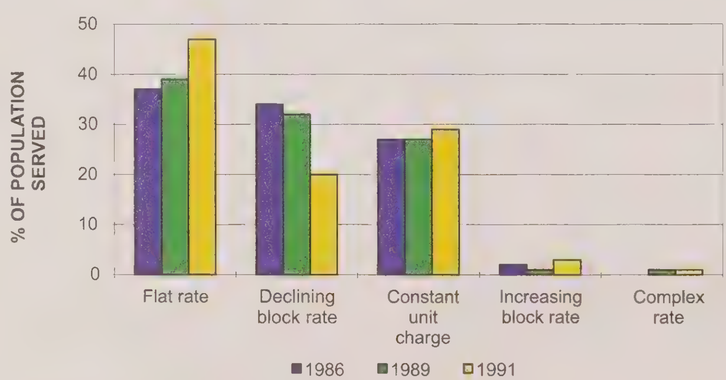
Statistics on the population served by treatment facilities may not provide the entire picture, however. In most Canadian cities, wastewater bypasses sewage treatment during heavy rainfalls, combining with stormwater in sewer overflows. The Sierra Legal Defence Fund (1994) reported that in Vancouver, Toronto, Winnipeg, Hamilton, and Ottawa — all of which have sewage treatment facilities — combined overflows totalled over 73 billion litres per year. Moreover, of the 20 major cities studied, only 2 claimed that overflows of raw sewage did not occur.

The water and wastewater services provided to Aboriginal people in Canada, particularly those living in the North, deserve special mention. In 1992–1993, about 91% of dwellings on Indian reserves had some form of potable water supply (piped, well, trucked, or other), and almost 83% of dwellings had sewage disposal facilities (Department of Indian Affairs and Northern Development 1993d). Although much progress had been made since the 1970s, this still left about 9% of reserve dwellings without a satisfactory supply of potable water and 17% without sewage disposal services.

Groundwater contamination

Sources of groundwater contamination can be classified as *point sources*, such as landfills, or as *non-point sources*, such as fertilized fields (Table 10.12). Aside from this distinction, the mobility and persistence of particular contaminants are important considerations. Road salt, for

Figure 10.19
Municipal water rate structures in Canada, 1986, 1989, and 1991



Notes: With a flat-rate pricing system, a fixed charge is levied regardless of volume used.
With a declining block rate, the price per unit of water decreases as more is used.
With a constant unit charge, the price per unit of water remains constant.
With an increasing block rate, the price per unit of water increases as more is used.
In a complex rate structure, there is a combination of declining and increasing block rates.

Source: Tate and Lacelle (1995).

example, is highly soluble and moves with the groundwater; on the other hand, pollutants emanating from sites contaminated with coal tar and creosote are readily adsorbed to soils and therefore are not likely to spread as far.

Most contaminants in groundwater have passed through the soil above the water table before entering the groundwater. Soils play a very important role in reducing the levels of contamination through biodegradation by soil organisms, adsorption on soil particles, and other processes. At many contaminated sites in Canada, contaminants reside mainly in the soil, and cleanup is concerned largely with the soils rather than with the groundwater. Furthermore, many point sources of groundwater contamination, such as excavations, buried pipelines, old unsealed test-drilling holes, seismic shot holes, and disposal wells, are very difficult to identify and locate.

Groundwater contamination often results from earlier inadequate management of wastes or industrial chemicals. In the 1980s, 175 known cases of groundwater contamination in Canada were studied. In 60% of these, contamination resulted from landfills, industrial waste sites, septic systems, deep-well injection of wastes, and other waste disposal, and over 20% resulted from seepage from underground storage tanks, spills, aboveground material storage, and other industrial operations (Statistics Canada 1994a).

In a limited survey of potential contaminated sites with dense organic chemicals in Canada, Cherry and Harman (1994) identified 92 such sites, which represent only a small fraction of the existing sites. Among the wide variety of industrial chemicals, dense, non-aqueous phase liquids (DNAPL), including solvents such as trichloroethylene and tetrachloroethylene, which are used in dry cleaning, constitute a particularly troublesome class of contaminants. They tend to sink deeply into the ground and then dissolve very slowly. These deep-seated sources of contamination are very difficult to find and almost impossible to clean up (Cherry and Harman 1994). Raven Beck Environmental Limited (1995) found that 56 of 481 municipal and communal groundwater supplies examined had detectable concentrations of either trichloroethylene or tetrachloroethylene.

Because groundwater moves slowly, it may be decades or longer before a contamination problem is detected — perhaps long after the source of the contamination has disappeared. By then, it may be very difficult to "clean up" the groundwater (MacDonald and Kavanaugh 1994).

In terms of the proportion of groundwater supplies that are affected, high nitrate levels and fecal coliform bacteria in wells represent the largest groundwater quality problem in Canada. Recent surveys suggest that 20–40% of all rural wells may be contaminated in this way. In the lower Fraser Valley, one survey found that 23 of 240 wells tested had excess nitrate concentrations (Gartner Lee Limited 1993); another survey found fecal coliform bacteria in 34 of 109 wells (Hii et al. 1994). Nitrates and bacteria were also found to occur throughout other parts of southern Canada, although with much variation in levels, depending on local conditions (e.g., Henry and Meneley 1993). In southern Ontario, it is estimated that 37% of all rural wells are polluted by bacteria or nitrates. The main sources of nitrate contaminants in groundwater are the application of fertilizers and manure to fields and

Table 10.11

Average concentrations of selected substances in municipal water supplies, 1990

	Concentration (mg/L)														
	Fluoride[a]			Chloride[b]			Nitrate[c]			Sulphate[d]			Aluminum[e]		
Province/territory	Raw	Treated	Dist.[f]	Raw	Treated	Dist.	Raw	Treated	Dist.	Raw	Treated	Dist.	Raw	Treated	Dist.
Newfoundland	0.10	0.77	0.71	2.98	6.15	6.16	0.27	0.30	0.26	1.89	1.88	1.89	0.18	0.11	0.12
New Brunswick	0.10	0.19	0.28	10.40	12.50	12.40	2.32	0.53	0.49	6.52	12.60	12.50	0.10	[illegible]	0.16
Nova Scotia	0.10	0.79	0.82	7.63	10.40	11.00	0.25	0.27	0.33	7.08	11.70	11.40	0.10	0.18	0.16
Quebec	0.10	0.19	0.17	15.10	17.60	20.50	2.10	2.01	2.22	14.60	25.40	25.60	0.23	0.12	0.11
Ontario	0.11	0.50	0.55	17.60	21.00	21.10	1.94	1.71	1.65	22.90	28.80	29.10	0.13	0.19	0.17
Manitoba	0.18	0.84	0.81	33.00	33.50	34.10	1.29	0.71	0.65	67.70	73.10	72.50	0.21	0.33	0.12
Saskatchewan	0.30	1.01	0.78	7.94	10.60	10.70	3.27	1.59	1.42	154.00	171.00	172.00	0.17	0.42	0.43
Alberta	0.18	0.85	0.85	11.80	14.70	14.30	2.89	1.41	1.87	52.70	69.90	69.30	0.45	0.21	0.28
British Columbia	0.24	0.50	0.50	1.96	2.81	2.81	0.78	0.84	0.80	8.78	8.79	8.71	0.18	0.17	[illegible]
Yukon	0.10	0.52	0.60	1.12	1.30	1.49	0.10	0.17	0.10	27.70	27.30	27.70	[illegible]	[illegible]	0.26
Northwest Territories	0.10	0.65	0.68	1.97	3.48	3.31	0.10	0.18	0.10	3.08	3.08	3.11	0.17	0.12	[illegible]

Note: No data are available for Prince Edward Island.

[a] The Canadian guideline value, or MAC (maximum acceptable concentration), for fluoride is 1.5 mg/L.

[b] MAC for chloride is 250 mg/L.

[c] MAC for nitrate is 45 mg/L (equivalent to 10 mg/L nitrate as nitrogen).

[d] MAC for sulphate is 500 mg/L.

[e] There is no Canadian guideline value for aluminum. The European standard is 0.2 mg/L.

[f] Water distributed by water supply system.

Source: Adapted from Statistics Canada (1994a).

leakage from septic tanks (Henry and Meneley 1993). Septic tanks and manure are probably also the main contributors to fecal coliform bacteria. Fecal coliform bacteria are not in themselves pathogenic, but they do indicate the possible presence of pathogens.

Agriculture has perhaps the greatest potential for diffuse or widespread effects on groundwater because of the large areas involved and because groundwater is the main source of drinking water in most rural areas. Concentrations of dairy cattle, poultry, and other livestock lead to heavy applications of manure, which may exceed the assimilation capacities of the soils, raising concerns about the quality of rural groundwater. Although farm use of chemical fertilizers and pesticides has increased in parts of Canada in the last two to three decades, there has been a sharp drop in total use and intensity of use in other areas, suggesting that the risks of water contamination from agricultural sources may have declined in some regions. In general, applications of pesticides to fields have not led to large-scale groundwater contamination. In the Ontario study mentioned above, pesticides exceeded acceptable levels in only 2 of 1 300 wells; in the lower Fraser Valley study (Gartner Lee Limited 1993), 4 of 240 wells tested contained pesticides, but only at very low concentrations.

Septic systems dispose of household wastes by degradation in holding tanks and subsequent seepage of effluent into the ground. Although domestic septic systems are small, the cumulative effects of many thousands of them may result in widespread contamination of shallow groundwater. This is particularly a problem in cottage areas and in outlying developments around cities, where municipal services are not available. Septic tanks can lead to narrow plumes of contaminated groundwater hundreds of metres long (Robertson et al. 1991).

Acid drainage occurs in nature when sulphide rocks or materials come into contact with atmospheric oxygen and water (e.g., through weathering and erosion). The exposure of sulphide-containing rocks may be accelerated by human activities, including mining and civil construction. Tailings from abandoned mines are of particular concern. Such acid will often seep into groundwater, which transports it and discharges it into nearby waters. This can have serious effects on aquatic organisms, particularly fish in their early stages. Local groundwater supplies are also occasionally affected.

Road salts provide a telling example of the delayed appearance and gradual buildup of groundwater contamination. In the Toronto area, for example, much of the shallow groundwater is contaminated with road salt, and the concentrations will continue to increase for many years as the salts are carried along with the groundwater and as more salt finds its way into the subsurface (Howard and Beck 1993). This salt contamination makes the groundwater unusable and will also affect wetlands and streams as the groundwater discharges.

Additional potential contaminant sources are likely to be identified, and many new cases of groundwater contamination will probably be reported. Cherry (1987) concluded that most known cases of serious groundwater contamination in Canada have come to light only when the unusual appearance or odour of water from a groundwater source became apparent or an obvious nearby contaminant source raised concerns. Very low concentrations of various common industrial chemicals have been encountered in about 10% of all wells that have been sampled in the course of large-scale surveys. The contaminant concentrations are generally considerably below those specified in drinking water guidelines, but these findings suggest that low-level degradation of the groundwater environment may be widespread. Not enough data are available to judge whether this low-level contamination is increasing or to positively identify the principal causes.

Groundwater may also be unfit to use owing to natural processes. During its travels through soil and rock, the groundwater picks up dissolved minerals that

Table 10.12
Potential sources of groundwater contamination in Canada

Non-point sources
Fertilizers on agricultural lands
Pesticides on agricultural lands and forests
Contaminants in rain, snow, and dry atmospheric fallout
Runoff of salt and other deicing chemicals from roads and highways
Point sources: waste disposal
On-site septic systems
Land spreading of sewage or sewage sludge
Municipal landfills
Leaky sewer lines
Livestock wastes
Sludge farming and sludge disposal areas at petroleum refineries
Waste rock and mill tailings in mining areas
Wells for disposal of liquid wastes
Fly ash from coal-fired power plants
Coal tar at old coal gasification sites
Disposal sites for industrial chemicals
Point sources: leaks and spills
Leaks and spills of industrial chemicals at manufacturing facilities
Leaky tanks or pipelines containing petroleum products
Asphalt production and equipment cleaning sites
Spills related to highway or railroad accidents
Chemicals used at wood preservation facilities
Road salt storage area

Source: Adapted from Cherry (1987).

may be undesirable or even toxic. For example, dissolved iron, which is common in groundwater, gives the water an unpleasant flavour and stains plumbing fixtures. In parts of Canada, arsenic, fluoride, and barium occur at concentrations high enough to render the groundwater unfit to drink. Unlike concentrations of artificial contaminants, the concentrations of such naturally occurring constituents are not likely to change over time. Most of the areas where they occur are known, and the substances can be detected and removed or avoided.

Where a groundwater supply is found to be contaminated, the usual response is to abandon it. However, the contaminated groundwater will continue to move and will eventually reemerge at the surface, where it may affect the quality of surface waters. For example, 215 hazardous waste disposal sites are located within the U.S. portion of the Niagara River drainage basin; for decades, toxic chemicals from these sites have been leaching via groundwater into the Niagara River, which feeds Lake Ontario (Kuntz 1993). Streams in agricultural areas can be affected by the nitrates in groundwater, because the groundwater contributes most of the water in such streams.

Protection of groundwater minimizes further contamination and the costs of future cleanup. Protection involves identifying, minimizing, or eliminating known sources of contamination, preventing new sources from developing, and monitoring to obtain early warning of contamination. Such measures have been taken or are under consideration in various regions and municipalities of Canada, including Regina, Saskatchewan; Kitchener–Waterloo, Ontario; Cap-de-la-Madeleine, Quebec; Prince Edward Island; Fredericton, New Brunswick; and Amherst, Nova Scotia.

The Canadian Ground Water Association, which represents well drillers across Canada, has recently issued guidelines for water well construction (Canadian Ground Water Association 1995) and for the proper way to abandon wells and test holes by sealing the holes. Application of these guidelines will help to reduce contamination of wells and groundwater.

There is a need for further identification of potential contaminant sources, long-term monitoring of selected wells and springs to identify trends, protection of groundwater in the context of integrated land use planning, and research on contaminant processes. Concentrations of contaminants may increase over the years as more contaminants move further into the groundwater reservoirs. Even where human health is not threatened directly, the effects of contaminated groundwater on ecosystem health must be considered, and this aspect of groundwater contamination remains poorly understood.

Biological "pollution"

Some exotic species alter the physical, chemical, or biological structure of freshwater ecosystems, with deleterious effects. These species may be considered "biological pollutants." Canadian lakes, rivers, and wetlands are being affected by a growing number of introduced species (e.g., the Zebra Mussel and Eurasian Watermilfoil). The "Wildlife" section of this chapter discusses the concerns related to exotic species, and Table 10.18 in that section lists a number of the most troublesome invaders, along with some of their notable effects.

Physical alterations: dams and diversions

Since ancient times, dams, canals, and diversions have been built to store and redistribute water and to facilitate navigation. They allow a controlled flow of water for energy production, irrigation, and flood control. Historically, Canada has been one of the main builders of dams and diversions, with 650 major dams completed or under construction in 1991 (Canadian National Committee of the International Commission on Large Dams 1984, 1991). Over 80% of the largest dams, as well as many of the diversions, are for electric power generation. The damming and alteration of rivers, while providing substantial economic benefits, have wide-ranging, long-term ecological consequences. These ecological effects may be divided into two basic categories: the effects of impounding water in reservoirs and the effects of altering natural patterns of streamflow.

Impounding water in reservoirs

Reservoirs involve the enlargement of existing lakes or the creation of lakes in former terrestrial or wetland ecosystems. In Canada, a combined area of about 20 000 km^2 (the size of Lake Ontario) has been covered by hydroelectric reservoirs (Rudd et al. 1993). Flooding of large tracts of land displaces people, disrupts wildlife habitat, and can even influence local climate and provoke small earthquakes (Day and Quinn 1992).

Reservoirs affect the quality and quantity of water in various ways. For instance, evaporation increases as the reservoir's surface area expands, reducing the total amount of water that flows downstream. Reservoirs also affect water temperatures and in some cases decrease the level of dissolved oxygen in the water. There can also be increases in nutrient loadings, with the potential for subsequent eutrophication. Among the consequences of these changes may be degraded habitat for many fish species and enhanced habitat for others. Silt that is normally carried downstream by a flowing river will settle in the slow-moving water of a reservoir; the productivity of ecosystems downstream may then fall owing to the reduction in nutrients normally provided by the silt (Statistics Canada 1994a).

Inorganic mercury in trace amounts is found naturally in soil and vegetation. As dead vegetation (organic matter) is being flooded by a new reservoir, it is decomposed by microbes in the water. At the same time and in a related process, microbes convert 1–15% of the mercury present into highly toxic, biologically available methylmercury (R. Hecky, Freshwater Institute, Department of Fisheries and Oceans, personal communication). The methylmercury accumulates and magnifies in food webs (see the discussion of the impacts of mercury in the "Wildlife" section of this chapter). The most notable end result is elevated mer-

cury levels in fish, making them unsafe for human consumption. Mercury in water and fish may not return to pre-reservoir levels for decades. Mercury poisoning has severe consequences for Indigenous populations reliant on fish as a primary food source and on fishing as a way of life. The removal of vegetation before flooding can help to control or reduce the amount of mercury released.

Elevated mercury levels from the construction of a reservoir were first discovered in the 1980s at the Churchill–Nelson hydroelectric project in northern Manitoba. They have since been found elsewhere, notably at James Bay, where a four- to sixfold increase in mercury concentrations was found in fish caught in the reservoirs (Government of Canada 1991c).

Fluctuating water levels in reservoirs and downstream are an unavoidable consequence of many hydroelectric developments and other dam-related undertakings. Such fluctuations can cause a variety of shoreline problems, most severely in areas of permafrost. Shoreline biological communities may not be able to establish themselves, erosion and turbidity may increase, and fish and other biota may be affected.

Dams clearly can lead to local and regional problems; however, the alternatives can also have environmental consequences. If, for example, hydroelectric power sites were to be replaced by coal-fired thermal power plants, there would be much higher emissions of greenhouse gases and toxic substances such as mercury to the atmosphere, with widespread adverse effects.

Altered natural streamflow patterns
Floods often cause economic and human disasters, but flooding is essential for the ecological balance and productivity of many riparian (river valley) and wetland ecosystems. Spilling over the floodplain, water nourishes these ecosystems and promotes their regeneration. They, in turn, capture and dissipate surges.

Efforts to control flooding by building dikes or hardened shorelines or by regulating streamflow with dams and diversions must be balanced against other needs: the preservation of habitats for fish and other wildlife, the functioning of entire ecosystems, and, particularly in northern regions, the way of life of Aboriginal people.

The Peace–Athabasca delta in northern Alberta, one of the world's largest freshwater deltas, provides a good example of an ecosystem whose balance depends on flooding and has been changed by damming. This delta is a key waterfowl staging and nesting area, as well as an important habitat for Bison, Moose, and various fish species. In the late 1960s, the Bennett Dam was constructed on the Peace River in British Columbia, 1 200 km upstream from the delta. Since then, the dam has been lowering the annual flood peak levels of the Peace River, significantly affecting this ecosystem. A successional trend has taken place, from wetlands to less productive terrestrial habitats, with consequent diminishment of biodiversity (Government of Canada 1991c; Environment Canada 1993b). Figure 10.20 illustrates how natural flooding in the delta has been reduced by upstream river regulation. Some remedial action (construction of weirs) has been undertaken to try to offset the ecological effects of the changes. Wetlands in the Saskatchewan River delta and in the Atlantic provinces have also been impacted by upstream dams (e.g., see Eaton et al. 1994).

Seasonal variations in the rate of streamflow play important roles in maintaining ecological functions. For example, high springtime flows scour fine particles from riverbeds, thereby providing clean gravel beds for the incubation of the eggs of fish. Dams change the natural pattern of flooding: they release more water during winter, when demand for energy is high, and less water in the spring. Resulting changes in water temperature, stream productivity, and river fauna also may affect salmon reproduction (Atlantic Salmon Federation and the Salmonid Council of Newfoundland and Labrador, undated; Whoriskey 1993).

Interbasin diversions, which transfer water from one river basin to another, may result in the transfer of fish, plants, parasites, bacteria, and viruses as well. Concerns about the transfer of foreign species from one basin to another have been instrumental in the decision to halt at least one major project — the Garrison Diversion project in North Dakota, which could have introduced biota from the Missouri system to the Hudson Bay watershed. Concerns related to introduced biota are examined in the "Wildlife" section of this chapter.

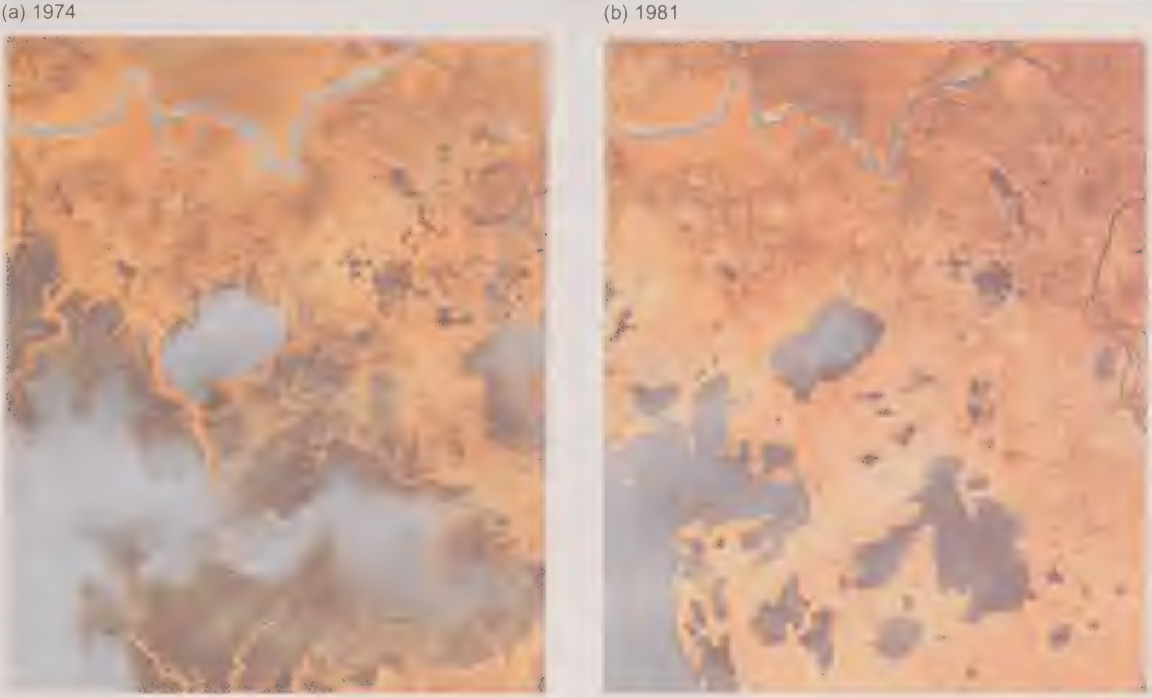
The future of dams and diversions
The era of big dams and diversions is probably drawing to a close in Canada. Between 1984 and 1991, only six large dams were constructed, some only after lengthy public discussions (e.g., Rafferty–Alameda, Oldman, and Laforge). Longstanding plans for the Kemano River (B.C.), Conawapa–Nelson rivers (Manitoba), and James Bay II (Quebec) have been shelved indefinitely (F. Quinn, Environment Canada, personal communication). Changes in economics, priorities, and political influence (particularly of Aboriginal people) have combined to make the construction of large dams and diversions less desirable and feasible.

However, there are still large unknowns surrounding the future of dams and water diversions in this country. These include the possibility of increasing demands for water as a result of climate change and pressures to divert water south of the border (e.g., see Linton 1993). There is also the likelihood of a significant jump in energy needs or a large shift to noncarbon energy production.

Biological indicators of the state of fresh water

The state of the species of plants and animals that inhabit a particular lake, river, or wetland serves as one measure or indicator of the overall state of that ecosystem (e.g., see Box 10.5 in the "Wildlife" section of this chapter). For example, when it is known that harvesting is not a determining factor, persistent declines in

Figure 10.20
Reduction in natural flooding of the Peace–Athabasca delta in northeastern Alberta as a result of the Bennett Dam



Note: The effects of the dam are significant, but variation in streamflow is also a factor, with 1974 having been a wet year and 1981 having been a dry year.

Source: Canada Centre for Remote Sensing, Energy, Mines and Resources Canada (taken from Andrews 1993)

populations of a species probably signify some form of ecological degradation. In addition, the number of endangered or threatened species in a particular area probably reveals something about the quality of the freshwater habitats upon which they depend. Table 10.19 in the "Wildlife" section of this chapter lists Canada's endangered and threatened species, many of which depend on freshwater habitats.

Developments in approach

Ecosystem approach
The way governments, nongovernmental organizations, and communities of all sizes address water issues is continually evolving. The trend is to a holistic, or ecosystem, approach, which emphasizes the processes by which components of ecosystems — air, land, water, wildlife, and people — interact with and influence one another. Canadian water research has long had this focus at places such as the Experimental Lakes Area (Schindler 1990), and researchers have formulated options for solutions to environmental problems such as acidic deposition and eutrophication.

Many of the federal–provincial river basin studies of the 1970s under the *Canada Water Act* had a comprehensive or ecosystem orientation. (Included were the Okanagan, Mackenzie, and St. John basins, among others.) Another early expression of this approach to water management came with the 1978 Great Lakes Water Quality Agreement between Canada and the United States, whose purpose is to restore and maintain the chemical, physical, and biological integrity of the Great Lakes basin ecosystem. Other expressions can be seen in the increasing emphasis on comprehensive land use planning, whole basin management, and regional development plans.

Basin-wide management
In many cases, freshwater ecosystems are best managed by the management of their drainage basin or catchment area (all the land and water from which water flows into the ecosystem of the river or lake). This is the region within which chemicals will be transported and freshwater biota, including exotics, will migrate.

Human settlements and industries have many impacts on freshwater ecosystems,

affecting water quality and ecosystem functions. Many of these impacts (toxics, nutrients, the spread of exotics) are predominantly felt nearby, within the boundaries of the drainage basin. For this reason, any effort to improve the health of a river or lake ecosystem will have to include the people who live there and consider all the activities taking place in the basin. Because drainage basins often overlap political boundaries, management plans typically involve the collaboration of more than one jurisdiction. Recognition of the need to forge political partnerships is an important aspect of the ecosystem approach (Royal Commission on the Future of the Toronto Waterfront 1992).

The ecosystem approach is currently being exemplified at many different basins throughout Canada. For the federal government, basin-wide action plans developed in conjunction with provincial governments have become a key management approach to cleaning up polluted ecosystems. Federal–provincial action plans are now in place for the Fraser River basin (Fraser River Action Plan), the watersheds of 13 sites being restored on the Atlantic coast (Atlantic Coastal Action Program), and the Great Lakes–St. Lawrence basin (Great Lakes–St. Lawrence Pollution Prevention Plan). In addition, the Northern River Basins Study is a Canada–Alberta–Northwest Territories partnership providing comprehensive ecosystem studies of the Peace, Athabasca, and Slave river basins. Important common elements of these programs include extensive involvement of all stakeholders, particularly Aboriginal groups, local communities, industries, and nongovernmental organizations, and an approach that links all aspects of the ecosystem.

On a smaller scale, people in local communities across Canada are discovering that management plans based on watersheds are a practical and effective approach to resolving environmental problems. The Salmon River Watershed in south-central British Columbia has experienced serious deterioration since the late 1800s as a result of the effects of logging, urbanization, and agriculture. Historically, the Salmon River was one of the largest salmon producers in the Fraser River basin. Today, the river's Sockeye Salmon population has nearly disappeared, and other species are in serious decline. Over a number of years, numerous studies have been conducted in the watershed by various government agencies. However, little remedial action has been possible owing to inconsistent policies among different governments and orders of government and failure to include landowners in decision-making processes.

Concerned local citizens recognized that restoration of the ecosystem's health would occur only when everyone living and working in the watershed began to work together. They established the Salmon River Watershed Round Table, whose underlying principles are respect for all stakeholder interests, cooperative action, and coordinated management of all resources in the basin. In a pilot project with the B.C. Ministry of Environment, Lands and Parks and Environment Canada through the Fraser River Action Plan, it is establishing a number of ecosystem objectives for the basin.

Initiatives like the Salmon River Watershed Round Table are being made by people in every province of Canada. Dozens of grassroots environmental groups have been formed around river basins or watersheds and are working to improve ecosystem health. The conservation authorities for each of the river basins in southern Ontario have a 50-year record of achievement in river basin management and in getting local municipalities in a shared basin to work together (Mitchell and Shrubsole 1992). One example is the Grand River Watershed Congress, formed in the late 1980s. The Grand River in southwestern Ontario is one of the designated heritage rivers under the Canadian Heritage River System, and the Congress coordinates the activities of nongovernmental organizations in its watershed (which includes the twin cities of Kitchener–Waterloo). One of its activities has been the design of a citizen-driven management plan for the watershed, which takes account of the river's heritage status (Linton 1993).

Federal freshwater strategy

At the request of Environment Canada, a review of the major water issues facing Canada in the coming decades has recently (August 1995) been completed. The major issues identified in the review dealt with water management (and the research and monitoring required for it) in a time of economic restraints and changes in the roles of governments (Bruce and Mitchell 1995). The federal government (Environment Canada in concert with the Department of Fisheries and Oceans) is now (February 1996) considering a new freshwater policy to complement an ocean strategy, which is also being developed.

Fresh water and sustainability

Fresh water is an essential resource for humanity. It is the fundamental basis of aquatic and related ecosystems. Without water, there is no life.

The question of sustainability of fresh water is essentially a question of finding a proper balance in meeting all the competing needs for water, of achieving a balance both among human uses and between human needs and the needs of natural ecosystems. Canada possesses a great wealth of fresh water in lakes and rivers, in wetlands, and in the ground. However, there are large regional differences in the distribution of water and in the environments of the people and wildlife that rely on it.

On the Canadian prairies and in the B.C. interior (particularly the Okanagan Valley), available water is limited, and sustainability concerns revolve around balancing competing uses. Traditionally, most water use in the prairies was for agricultural irrigation. Today, agriculture is competing for scarce water with the growing needs of cities, the demand for energy production, and the desire of citizens to preserve natural ecosystems. Full-cost accounting may be the best approach to provide an economically sustainable distribution of the resource, but it will require improved methods of putting a value on nonmarket values such as healthy ecosystems. The concerted action of individuals — farmers foremost

among them — may be the best way to preserve natural ecosystems. The Prairie Habitat Joint Venture and the discussions surrounding the construction of the Oldman and Rafferty–Alameda dams show that citizens can organize themselves for effective action on water issues (see Chapter 4). Government resources, however, will still be needed to collect basic data on water quality and quantity.

In the most populated and industrial regions of the country (the Windsor–Quebec City corridor, or Mixedwood Plains ecozone, and parts of the Pacific and Atlantic coastal ecozones), water is plentiful. There, unsustainable water use appears as impaired water quality, as physical modifications to aquatic habitat, and as unrealistically low costs for water infrastructure. Low levels of persistent organic toxic compounds such as PCBs in the waters and sediments of the Great Lakes and St. Lawrence and of chlorinated solvents (DNAPLs) in groundwater at such sites as Mercier, Quebec, are an unintended by-product of past industrial development. It is not clear how best to deal with this poisonous inheritance. In these regions, as in others, the solution to the problem of escalating costs of water infrastructure is likely to be full-cost accounting and the resulting efficiencies of use. Full-cost accounting might also go a long way towards pollution prevention, by making people financially accountable for the impacts of pollution.

In the North and other less populated regions of the country, the primary issue is the impact of contaminants transported from far away into fragile environments. The impacts of acidic deposition will be diminished but not eliminated under the agreed emission limits. Other long-distance pollutants threatening the North's water are toxic metals and persistent organic compounds, which are transported from industrial areas throughout the northern hemisphere. Another northern issue is the potential for tailings at the sites of closed mines to generate acid drainage, now or at some future date. Today, however, the closure of a mine in Canada includes the implementation of reclamation plans that would address this issue. These reclamation plans are often initiated before a mine is actually closed.

Groundwater is a crucial link in the hydrologic cycle and in the movement of contaminants. The threats to groundwater encompass the legacies of the past (gasoline storage tanks, chlorinated solvents, road salt, etc.) as well as newer dangers (nitrates and pathogens). Bacteria and other pathogens in well water may be a particular threat to the health of certain populations, such as Canada's Aboriginal people.

A changed economic climate is forcing this country into a reevaluation and restructuring of water-related monitoring programs. It is essential, for economic as well as environmental reasons, to be able to monitor the threats to freshwater ecosystems, as well as the success of remediation and prevention activities.

The management of boundary waters provides one example of the need for ongoing monitoring. As more than 80% of Canadians live in river basins shared with the United States, the management of these boundary and transboundary waters has a profound effect on Canada and its people. Issues related to these waters are managed under the Boundary Waters Treaty of 1909. At present, there are 32 water-sharing or water pollution control agreements under this treaty. Boundary water issues require continuing measurement and assessment programs to protect Canadian interests and ensure that both countries live up to their obligations (Bruce and Mitchell 1995). Monitoring will also be required to assess the need for regional and transnational redistribution of water resources, particularly in light of predictions of future climate change. On a larger scale, some form of monitoring is needed to understand the global water balance and for Canadians to assume their share of responsibility for global water issues.

Since projections of climate change suggest that both frequency of heavy rains and lengths of dry spells may increase in many regions, attention to flood and drought control programs will become all the more important. A major policy initiative of the 1970s was the federal–provincial Flood Damage Reduction Program, which resulted in mapping of floodplains in many municipalities and the restriction of building in these floodplains. This program, which has been a model for other countries, has succeeded not only in reducing flood losses, but also in preserving many river valleys in high-population regions for wildlife habitat and recreational activities. Drought programs (such as those under the federal *Prairie Farm Rehabilitation Act*) have been concentrated in the Prairie provinces. The programs focus on water conservation measures, such as building farm ponds, that are beneficial to wildlife.

The country has made progress in reversing, or at least slowing, the degradation of its freshwater resources. The main success stories to date are the significant reduction in persistent toxic compounds since the 1970s in the Great Lakes and other water bodies and the increasing understanding and control of nutrient contamination. It is too early yet to assess the success of the acid rain control programs on aquatic ecosystems.

Another positive step is the increased acceptance of an integrated approach in dealing with water-related issues. Compared with the 1970s and 1980s, today's land use plans and conservation strategies tend to be more ecosystem oriented and regionally based. Regional action plans are in place for major drainage basins such as the Fraser River and the Great Lakes–St. Lawrence. Shared government–community responsibility for projects is also an encouraging trend.

Oceans

A maritime nation also

Canada is a large country, with an abundance of terrestrial and freshwater resources. But Canada is also very much a maritime nation. It has the world's longest coastline, at 243 792 km (Energy, Mines and Resources Canada 1989), and the second largest continental shelf, with an area

of 3.7 million square kilometres. Its shores touch on three of the world's five oceans — the Pacific, the Arctic, and the Atlantic. Canada also has one of the largest exclusive fishing zones, encompassing approximately 4.7 million square kilometres of ocean (Wells and Rolston 1991).

Canada, therefore, is blessed with a large proportion of the world's coastal and marine resources. These have contributed substantially to the nation's economic growth. However, the significance of oceans to Canada and other countries extends beyond the economic value of the resources contained in territorial waters. More importantly, oceans play a key role in global ecological processes that influence life and living conditions throughout the world.

This section of Chapter 10 looks at the ecological and socioeconomic importance of the oceans. It discusses the main environmental issues associated with human activities and, where possible, describes what is being done to reduce adverse environmental and socioeconomic effects. It presents the ecological context of the marine environment and addresses the problem of sustainable development, including the progress made so far.

The role of oceans in global ecological balances

Oceans are essential to global ecological processes such as the hydrologic cycle (see Fig. 10.15 in the "Fresh water" section). This ecological significance is largely a product of their enormous size and depth. Oceans cover nearly 71% of the Earth's surface, average about 3 700 m in depth, and contain 1.4 billion cubic kilometres of water (Lemonick 1995). This amounts to roughly 97% of the world's total water supply.

This huge volume of water has the capacity to store and transport large amounts of heat and material. A kilogram of water, for example, can hold four times as much heat as the equivalent amount of air. Because of its greater density, a column of water only 2.5 m deep can hold as much heat as the entire atmospheric column above it (Wright et al. 1994). The oceans' heat storage potential is therefore very large, so that even minor variations in ocean water temperature can have major effects on atmospheric temperatures and hence on the global climate system. "Short-term fluctuations in climate, for instance, are often associated with changes in ocean currents or sea surface temperatures. One of the best-known examples of this effect is the El Niño phenomenon, which is marked by a pronounced warming of surface waters in the eastern and central portions of the tropical Pacific" (Environment Canada 1995c). By transferring enormous amounts of heat to the atmosphere, El Niño disrupts global circulation patterns and significantly alters regional climate conditions, changing rainfall patterns and making some areas hotter and others cooler. Such minor variations in ocean water temperature can occur in long-term cycles, which have a profound effect on the structure and productivity of the open ocean ecosystem.

Ocean waters absorb heat during warm periods and release it during cooler periods, moderating the climate of adjacent land masses. Like the atmosphere, the oceans also redistribute heat by transporting it from the tropics to the polar regions.

Although ocean currents move much more slowly than atmospheric weather systems, the greater heat retention capacity of water makes the amount of heat transported by oceans across mid-latitudes approximately equivalent to the amount transported by the atmosphere (Wright et al. 1994). This south–north heat transport occurs through two different mechanisms — large wind-driven currents essentially operating horizontally in the surface layer of the oceans, and a deep-water circulation flowing from regions of higher density to regions of lower density, moving water vertically from top to bottom as well as laterally around the globe. This second, overturning circulation has been called the global conveyor belt. Dense, cold water, especially in the North Atlantic and around Antarctica, sinks and moves towards areas of lower density, generally at lower latitudes, where it warms and gradually rises into the surface layer. The net flow of surface water moves back towards the deep-water formation areas, where it releases heat to the high-latitude atmosphere. It has been estimated that, without this overturning circulation, the air temperature over the North Atlantic would be as much as 10°C lower than it is today (Manabe and Stouffer 1988, cited in Wright et al. 1994).

In addition to their role in climate regulation, oceans also benefit life on land by regulating the chemical balance of the atmosphere. Marine organisms, for example, produced the atmospheric oxygen that made it possible for terrestrial lifeforms to evolve. Marine photosynthetic activity continues to produce close to half the current global oxygen supply.

The interaction between the oceans and the atmosphere with respect to carbon dioxide is equally important (see Box 10.2). Oceans absorb carbon dioxide, which is used in photosynthesis and, as a result, is accumulated in the biomass of marine organisms. One of the outcomes of this process is phytoplankton and seaweed (algae) productivity, as species of these groups are the dominant photosynthesizers in the marine environment. Although oceanic ecosystems have low productivity compared with terrestrial systems, the world's oceans are so large that they contain, in total, 20 times as much carbon dioxide as terrestrial systems. About 90% of this carbon dioxide is recycled in the food web, but some of the biomass containing it falls to the ocean bottom and accumulates in sediments, effectively removing the carbon dioxide from the system. It is estimated that about a third of anthropogenic carbon dioxide is retained in the oceans, attenuating the buildup of atmospheric carbon dioxide and, hence, the greenhouse effect.

Many other chemical and particulate materials enter the marine environment from land-based sources, by direct discharge, through rivers and streams, or through atmospheric transport and precipitation. Oceans assimilate most of these inputs through the process of decomposi-

tion, by which bacteria and other microorganisms consume chemical nutrients and degrade organic matter into its chemical constituents. Synthetic chemicals, however, may not be biodegradable and hence may accumulate in sediments or in living organisms, sometimes with toxic effects. Even organic wastes pose a problem by stimulating productivity, potentially overwhelming the assimilative capacity of the local environment.

Life on this planet originated in the oceans and has been evolving there for 3.5 billion years, compared with only 450 million years on land. As a result, a much greater diversity of life has developed in the marine environment — at least at the higher taxonomic levels. Of the 33 phyla (major taxonomic divisions) known to science, 15 exist exclusively in the oceans and another 5 are at least 95% marine.

Less is known about marine life at the species level, but some studies indicate that oceanic biodiversity may be as high as or higher than that of tropical rain forests. The density of species in a given area is much lower, but the oceans are so vast that the total count is very high. This storehouse of biodiversity is relatively unstudied and provides vast potential for research; already, antileukemia drugs have been derived from sea sponges, and anti-infection compounds have been found in shark skin.

Oceans are a key source of food for human consumption (e.g., see Chapter 11). Areas of highest productivity are generally along coastlines; areas of upwelling and the waters over continental shelves, in particular, provide some of the most productive fisheries. However, although coasts are the most important areas of biological activity, they are also where human activity is concentrated. Coastal zone management, particularly the cumulative impacts of human activities, is therefore becoming an increasing focus of concern.

The oceans and Canada's social and economic development

Oceans greatly influence how Canadians live. For instance, shipping plays a vital role in Canada's national and international trade. In 1993, more than 225 million tonnes of cargo were handled in Canadian ports. Table 10.13 shows tonnage of cargo for selected ports.

The fisheries sector is probably the most significant economic sector along Canada's coasts. In 1993, more than 1.3 million tonnes of fish were removed from the sea, representing a landed value of more than $1.4 billion. That same year, Canada exported more than $2.4 billion of fish products (see the "Fisheries" segment of Chapter 11). Although some of the historically stable fisheries have been reduced or placed under a moratorium, the harvest of species that formerly were not harvested in appreciable amounts is leading to the development of new markets. Such diversification has helped some coastal communities compensate for economic losses as a result of the population collapse of a single target fish, such as cod. However, it is adding other pressures on marine biota (see Chapter 11). There is a need for a multispecies or ecosystem approach to the management of the marine harvest that takes into account natural cycles in productivity.

The oceans are also part of important cultural values, as represented by the traditional way of life of people who fish for a living and of Canada's Aboriginal people, and by their recreational significance to Canadians (see Chapter 11).

Just as oceans affect the way Canadians live, people influence the oceans. The expanding population in coastal areas (Fig. 10.21) and the economic development that accompanies this growth contribute to increasing pressures on marine ecosystems, as do offshore exploration for fossil fuels and the extraction of sand, gravel, and minerals. Marine ecosystems, both nearshore and offshore, are currently under a variety of pressures, which vary in scale and intensity. Some of the key issues are discussed in the following sections.

Climate variability and change

Current evidence indicates that the Earth's climate is warming (Environment Canada 1995c; see also the "Atmosphere" segment in this chapter and Chapter 15). The role of the oceans in long-term climate variability is just now being investigated, but it is clear that the oceans will be a prime determining factor of climate change and its impacts, including those at high latitudes, where temperature increases are predicted to be much higher than global averages.

Box 10.2
Carbon dioxide and the sea

Between 1850 and 1993, carbon dioxide in the atmosphere — the primary source of carbon dioxide entering the oceans — increased by more than 25%, mainly from anthropogenic sources (see Chapter 15). In 1992, an estimated 7.1 billion tonnes (7.1 Gt) of carbon from anthropogenic carbon dioxide were released globally, most of which (5.5 Gt) was due to the burning of fossil fuels.

Of this carbon dioxide of anthropogenic origin, measurements have indicated that 57% accumulated in the atmosphere, with the remainder ending up either in the terrestrial biosphere or in the oceans. It has been calculated that the average net ocean uptake of carbon dioxide is in the order of 2.1 Gt per year, which represents 41% of the carbon dioxide generated globally per year from anthropogenic sources. Thus, the oceans are the dominant sink or reservoir for anthropogenic carbon dioxide. In the oceans, carbon dioxide exists in three basic forms: dissolved gaseous carbon dioxide and carbonates account for 5% and 10% of the total, whereas bicarbonates account for 85%. Consequently, most of the anthropogenic carbon dioxide entering the oceans ends up as bicarbonates.

Source: Quay et al. (1992); Wong and Matear (1993).

Table 10.13

Tonnage of cargo loaded and unloaded by Canadian region: international shipping, 1988–1993

Year	Amount of cargo (t)								
	Vancouver	Sept-Îles/ Pte. Noire	Port Cartier	Saint John	Halifax	Quebec/ Lévis	Subtotal[a]	Others[b]	Total[c]
1988	70 317 229	23 043 187	22 477 459	14 696 416	14 779 600	17 869 194	163 183 085	64 733 590	227 916 675
1989	63 752 642	23 325 400	21 290 470	14 588 679	16 313 076	15 367 548	154 637 815	57 791 814	212 429 629
1990	64 486 499	21 346 533	20 580 772	14 443 995	16 837 224	17 124 452	154 819 475	59 400 790	214 220 265
1991	68 347 598	21 418 347	22 845 922	17 100 428	14 199 766	18 090 924	162 002 985	56 448 045	218 451 030
1992	61 314 756	19 194 851	21 312 762	15 639 102	13 774 990	15 659 824	146 896 285	54 560 369	201 456 654
1993	58 877 732	21 018 854	19 269 777	19 266 174	14 178 319	13 178 495	145 789 351	50 806 663	196 596 014

[a] Total of the seven leading ports.
[b] The remaining three leading ports.
[c] Total of the 10 leading ports.

Source: Statistics Canada (1992, 1994d).

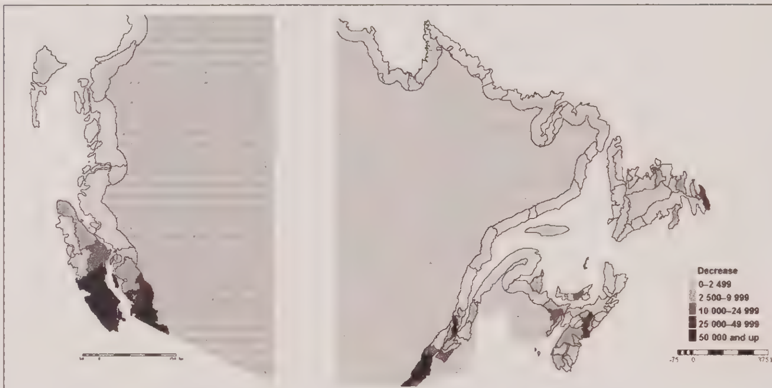
Sea surface temperatures

There is some evidence of sea surface temperature change within Canadian coastal waters. In the Pacific region, a warming trend of approximately 1.2°C per century has been recorded (Freeland 1990). On the west coast of Vancouver Island, sea surface temperatures recorded since the mid-1930s show a seasonal fluctuation between 7°C and 14°C, which is normal. However, these waters also experience large fluctuations over time frames of decades and longer. These variations, termed temperature anomalies, are usually classified as higher or lower than average. At the site of long-term records for the Pacific Ocean, the sea surface temperature trend has generally been higher than average (Fig. 10.22). However, it is unclear whether the rise is due to human-induced global climate change or is a response to a centuries-old natural cycle in ocean circulation and temperature. Harding (1992) and Angle et al. (1994) noted a lower than average temperature trend for the Atlantic region since 1940. This cooling area is consistent with the projections of recent climate models. No long-term temperature records are available for the Arctic.

Ocean temperature changes that occur naturally have a major impact on the distribution of marine biota. For example, there are two main migration routes for Pacific salmon returning to spawn in the Fraser River. When sea surface temperatures are warmer, such as during an El Niño event, salmon choose the north end of Vancouver Island to approach the coast of British Columbia. Under cooler conditions, a more southern approach is taken (Groot and Quinn 1987). Human-induced climate change could lead to new distribution patterns for marine biota, with serious ecological consequences for the biota and economic consequences for their harvesters (Harding 1992; Angle et al. 1994; Department of Fisheries and Oceans 1994). In the Arctic, rising ocean temperatures would likely result in northward expansion of the distributions of Walrus, Bowhead Whale, Ringed Seal, and Bearded Seal and increasing fish and Harp Seal numbers (Harrington 1986).

Figure 10.21

Population change within 50 km of Canada's coastlines, 1971–1991



Source: Special tabulations prepared by Statistics Canada based on the 1971 and 1991 Censuses of population.

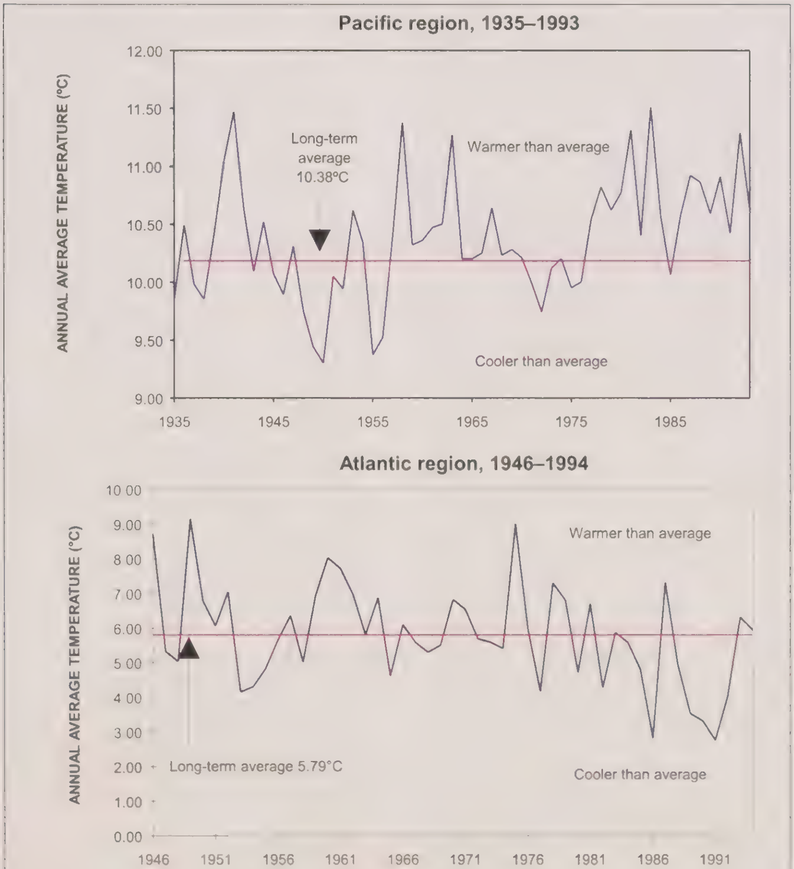
Sea levels

Climate warming could lead to thermal expansion of the water, disintegration of polar ice sheets, and melting of glaciers and ice caps, with a consequent rise in mean sea level. Since the early 1890s, the average rate of rise of global sea level has been 1–2 mm per year, or 10–20 cm over the century (IPCC 1990). It has been estimated that continued greenhouse warming could cause the world's sea level to rise at a rate of 1–11 cm per decade over the next century (see discussion in Chapter 15). This could cause

flooding in low-lying areas and increase coastal erosion, especially in eastern Canada. The environmental and socio-economic impacts could be enormous.

More research on climate change is needed to reduce uncertainties in the prediction of sea level rise. Actions are also required to further an understanding of the impact of sea level rise. These include developing detailed inventories and maps of coastal infrastructure and natural resources in areas potentially affected and encouraging those involved with coastal zone management, building standards, property zoning, and sustainable development planning to take into account the possibility and potential effects of rising sea levels. The Department of Fisheries and Oceans is undertaking various research studies to assess the potential impacts of a changing climate on fisheries.

Figure 10.22
Sea surface temperature variations for the Pacific region, 1935–1993, and for the Atlantic region, 1946–1994



Note: Atlantic region: Sea surface temperature (0–10 m) at station 27 off Newfoundland.

Source: *Pacific region*: Department of Fisheries and Oceans, Sidney, B.C.;
Atlantic region: Bedford Institute of Oceanography, Department of Fishenes and Oceans, Dartmouth.

Sea ice

The area of permanent ice over the Arctic Ocean decreased by about 2.1% over the last 10 years of examination. In other words, the retreat of ice cover, averaged over all regions in the Arctic, was about 22 km (Gloersen and Campbell 1991). Such a decrease is consistent with expectations related to climate warming. However, natural fluctuations and many other parameters are not well enough understood to confirm whether the changes in sea ice cover are due to climate warming or are simply an example of normal fluctuation (Gloersen and Campbell 1991). The thickness of sea ice is also subject to considerable variation. A record of coastal ice in the Canadian Arctic that goes back more than 30 years has revealed no trends in thickness attributable to climate warming (Brown and Cote 1992). In the drifting ice of the Arctic Ocean, the record of ice thickness is too short to detect temporal trends in thickness (McLaren et al. 1990; Wadhams 1990).

Pollutants

Persistent litter and debris

Since their introduction into general use, plastics have found their way into debris accumulating in the environment. Canada, like many other nations, has a problem with persistent plastic debris in its marine environment (see Box 10.3). Marine debris kills marine life through entanglement, snaring, or being mistaken for food; it also fouls propellers, clogs water intakes, and blocks pumping systems. Coastal communities incur costs for regular maintenance, such as litter collection. Estimating the extent of the problem and finding its sources pose some unique challenges. Data collection is difficult along the longest coastline in the world, and information is correspondingly scarce.

Since the 1980s, research activities have been largely a volunteer effort, with government shore surveys providing some detailed information from one-time efforts. Although statistically valid trend data are scarce, all the surveys clearly illustrate that a problem exists. Each year, debris in various forms is found on Canadian beach-

es and on the high seas. The many sources include boaters; beach and park visitors; fishing, cargo, and passenger vessels; and sewage discharges. As well as the debris that we can readily see, an additional problem is posed by the presence of pellets of plastic resin. The pellets threaten seabirds, because they can easily be ingested (Ryan 1987). Often these pellets must be specifically searched for owing to their small size, and they tend to be overlooked during surveys. Industry has been making efforts to reduce the release of resin pellets, for, in addition to the environmental problems, such releases represent a loss of saleable product.

Environment Canada and Pitch-In Canada, a national environmental group, are working with some 40 volunteers on the east and west coasts to gain a more precise understanding of trends in the nature and sources of marine debris. In addition, Environment Canada is promoting responsible action by communities and environmental groups to deal with the problem.

Box 10.3
A quick tour of marine debris

Sable Island lies in the Atlantic Ocean, about 300 km southeast of Halifax. Beach surveys carried out there from 1984 to 1986 and in 1991 recovered a total of 11 183 items of debris. The average accumulation was 219 items per kilometre per month. Of the items found, 92% were made of plastic. They included netting, rope, cups, pellets, bags, soft-drink bottles, and food and oil containers (Lucas 1992). On the mainland, the Clean Nova Scotia Foundation has conducted beach sweeps since 1989. Plastics, polystyrene foam, and rubber made up 63.6% of the materials found (Clean Nova Scotia Foundation 1993). In 1993, the Department of Fisheries and Oceans conducted a survey of debris found along the St. Lawrence River in Quebec (Department of Fisheries and Oceans 1993). Much of the debris consisted of plastics (61% by weight, 85% by volume and item count) and could be attributed to nearby activities.

On the Pacific coast, the B.C. Coastal Clean Up Campaign has undertaken regular cleanups on southern Vancouver Island and the Strait of Georgia. Plastics accounted for 44% of the debris found on beaches in 1990 (Eade 1992). Presumed sources included recreational boaters, fishing and cargo vessels, cruise and passenger vessels, tourists in parks and on beaches, and municipal discharges. Staff at Pacific Rim National Park, on the west coast of Vancouver Island, have conducted litter sweeps of the park since 1989 and have noticed a decrease in the debris collected. In 1993, 1 360 kg were recovered, compared with 1 800 kg in 1992 and 2 270 kg in 1991. About 77% of the debris was polystyrene foam and plastic. Items typically found include bait bags, outboard motor oil cans, water jugs, and food packaging (B. MacIntyre, Pacific Rim National Park, Vancouver Island, personal communication).

In Canada's Arctic, Environment Canada performed aerial surveys of the Tuktoyaktuk Peninsula and the Beaufort Sea in 1985. The surveys, which were conducted before and after the oil drilling season, noted different debris from that found on the west coast and in Atlantic Canada. Over 90% of all debris was derived from oil and gas exploration activities. One aspect was the large number of metal fuel drums present onshore. The surveys made 127 sightings of debris before the drilling season and 213 after (Shearer and Bourque 1987). In 1990, the entire Tuktoyaktuk Peninsula, from its eastern tip to the Alaska border, was surveyed by helicopter, and a number of sites were surveyed on the ground. Commonly found items were polystyrene foam and polypropylene rope. More recently, with the decline of oil and gas exploration in the Arctic, the largest source of debris appears to be domestic waste from shoreside communities (J. Eamer, Environmental Conservation Service, Environment Canada, personal communication).

PCBs

PCBs and other synthetic organochlorines commonly contaminate the sediments of harbours and major river systems discharging to the sea (Wells and Rolston 1991). The ecological damage resulting from their extreme persistence in the environment led to tight controls on manufacture and use as early as the 1970s. Virtually all the PCBs that have escaped into the environment are still there. Although the effects of PCBs on humans are not yet fully understood, the long-term risks of even low-level exposure warrant concerted efforts to reduce their levels in the environment (Eaton et al. 1994).

PCBs are widespread in the Atlantic coastal region, from both sediments and airborne sources, and concentrations up to several hundred parts per million (ppm) wet weight in Beluga have been observed. Calculations based on total rainfall over the Gulf of St. Lawrence, concentrations of PCBs in rainfall, and typical river concentrations of PCBs suggest that about 50% of the input of these chemicals to the Gulf of St. Lawrence is through the atmosphere (Bidleman et al. 1992).

In the Pacific coastal region, the lack of published data on PCBs markedly detracts from the understanding of their significance (Waters 1988). PCBs have been detected in the leg muscle of edible crab and in fillets of flounder, salmon, sanddab, and other fish (Garrett 1985). The Health Canada guideline for PCBs in shellfish and finfish is 2.0 ppm wet weight (Wells and Rolston 1991).

In Canada, PCBs are regulated through CEPA and the *Transportation of Dangerous Goods Act* and are monitored and controlled through a cradle-to-grave (from generation to ultimate disposal) approach. It is expected that this approach, along with new disposal methods, will aid in the reduction of contamination.

Metals

Metals occur in the marine environment naturally and as a result of human activities (see Chapter 13). Many metals are essential to life, but others, such as lead, cadmium, antimony, thallium, and mer-

cury, do not appear to have a nutritional or biochemical function. Although the presence of these elements in low concentrations does not normally give rise to any toxic effects, under certain environmental conditions, greater quantities of these metals can be dissolved or otherwise transformed into biologically available forms that can have adverse effects on plant or animal growth and health. In addition to the redistribution of metals through natural processes, potential anthropogenic sources of metal pollution include offshore oil and gas development, industrial effluents, municipal wastewater discharges, urban runoff, mining facilities, ocean dumping, and volatile emissions from incineration and combustion that reach the oceans via the atmosphere.

Scientific investigations have not demonstrated any human illness or reduced fish stocks as a consequence of mine tailings disposal in the Pacific coastal areas of Canada (Wells and Rolston 1991). However, ocean disposal of mine wastes has led to alteration of marine fish habitats in British Columbia (e.g., at Britannia Beach and Rupert Inlet; S. Samis, Institute of Ocean Sciences, Department of Fisheries and Oceans, personal communication). Mine tailings disposal has caused considerable habitat degradation in Nova Scotia, New Brunswick, and Newfoundland, and, in certain areas of New Brunswick, levels of copper and zinc remain sufficiently high to kill fish (Eaton et al. 1994). In 1977, the federal Metal Mining Liquid Effluent Regulations (MMLER) came into force, with the goal of ensuring that base metal, uranium, and iron ore mines operating in Canada apply the most practical and recent technology to ensure that their liquid effluents meet regulatory concentration limits (see Chapter 11). The regulations apply to new, expanded, or reopened mines as of 1977. The Guidelines for the Control of Liquid Effluent from Existing Metal Mines describe the same effluent contaminant limitations for mines in operation prior to 1977 that are specified by the MMLER. A general description of the main metal contaminants of concern for the marine environment is presented in the 1991 edition of this report (Government of Canada 1991c).

In addition, tributyltin (TBT), a toxic organic compound containing tin, has exhibited negative effects on marine life. TBT, which was previously used in most antifouling paints (see Box 13.1 in Chapter 13), has been found to leach out of painted surfaces. The effects include imposex (the imposition and development of male reproductive structures in the female) in snails and shell thickening in gastropods in general — two significant marine issues. Chapter 13 outlines some significant biological effects of TBT, especially on whelks and oysters. In Canada, concerns related to the health of marine biota resulted, in 1989, in certain TBT bans under the *Pest Control Products Act*. Along the Pacific coast, controls on the use of TBT-based paints appear to be taking effect (e.g., see Box 13.1 in Chapter 13).

Spills

Ocean traffic and industrial operations along the coast (e.g., pulp and paper mills) are the source of most spills. Spills usually consist of either petroleum products or nonpetroleum compounds such as industrial chemicals and process effluents. Oil spills occur most often in harbours; however, sea transport accidents can result in major environmental impacts on coastal and open ocean ecosystems. In the Arctic, the annual sea lift of fuel and other supplies to remote communities and industries constitutes one of the largest sources of oil contamination. Elevated levels of hydrocarbon contamination have been documented for specific Arctic areas (Wells and Rolston 1991), and bioaccumulation in benthic fish species such as flounder has been identified (Packman and Shearer 1988). Except for the immediate areas around spills, oil in the ocean environment is generally found in such low concentrations that it does not pose an immediate threat to marine life. The long-term impacts of oil pollution and the recovery of oil-impacted habitats, especially in Arctic areas, are now being studied.

Pulp and paper mill discharges

The production of pulp and paper generates organic and toxic wastes, which are regulated under the revised Pulp and Paper Effluent Regulations pursuant to the *Fisheries Act* and under the CEPA dioxin and furan regulations. In 1994, Canada stipulated that all mills must undertake an Environmental Effects Monitoring Program, pursuant to the revised Pulp and Paper Effluent Regulations. The objective is to ensure the adequacy of effluent regulatory standards for protecting fish, fish habitats, and human use of fish.

Impacts from pulp and paper mill discharges include the buildup of wood fibre in the receiving waters. The dissolved oxygen available to fish can be used up by the decomposition of organic materials in the effluent, and benthic habitats can be smothered. Depending on the production process, pulp and paper mills may also be major sources of toxic chemicals, including dioxins and furans. These chemicals have been found in the fatty tissue and muscle of crab and other shellfish in the Pacific region, with the result that some commercial and noncommercial fisheries were closed, beginning in the late 1980s (see Chapter 3). However, in February and August 1995, the Government of Canada announced reopenings of certain closed fisheries because of reduced dioxin and furan levels in shellfish tissues (e.g., the crab fishery at Howe Sound in the Strait of Georgia). These improvements were the result of significant process changes by industry in response to the federal dioxin and furan regulations (S. Samis, Institute of Ocean Sciences, Department of Fisheries and Oceans, personal communication).

Nutrients, eutrophication, and natural biological toxins

Runoff of agricultural fertilizers and animal wastes, aquacultural operations (hatcheries and cage sites), municipal effluents, and industrial wastewater (e.g., from the food-processing industry) are primary sources of elevated levels of nutrients such as nitrogen and phosphorus in the oceans. However, atmospheric

deposition of nitrogenous compounds can be the main source of nitrogen loading in some nearshore areas. Nutrients are critical to sustain marine plant growth, but inputs of large quantities can create eutrophication. Algal blooms resulting from eutrophic conditions soon die off and subsequently decompose, during which large amounts of oxygen in the water are used up. These increases in biochemical oxygen demand (BOD) can result in hypoxia (deficiency of oxygen in the water), with implications for the biota of these waters. In British Columbia's marine waters, hypoxic conditions are usually the result of effluent BOD being exerted within embayed waters (S. Samis, Institute of Ocean Sciences, Department of Fisheries and Oceans, personal communication). BOD from pulp mill effluent and fish-processing waste discharges has rendered some B.C. inlets with comparatively low flushing rates seasonally hypoxic.

Some phytoplankton species produce toxins under bloom conditions. These toxins are generally not toxic to marine life itself, but they can be markedly toxic to top predators, including humans who consume contaminated organisms. Paralytic shellfish poisoning (PSP) is one example of this. Seabird deaths have been attributed to PSP outbreaks in Barkley Sound, British Columbia. Increased eutrophication owing to coastal zone development could lead to more outbreaks of PSP. Indeed, each year, cases of mollusc poisonings as a result of microbiological and algal contamination are reported to public health authorities in Quebec (D. Bolduc, Comité de santé environnementale du Québec, Centre de santé publique de Québec, personal communication).

Municipal wastewater

Municipal wastewater is still one of the major sources of marine contamination in Canada. The damage is primarily in the form of sediment toxicity, changes to the structure and abundance of benthic invertebrate communities, and effects on fish health. Municipal wastewaters (including storm sewers) are a source of organic and metal toxic substances. In addition, inadequately treated municipal wastewaters contain bacteria, viruses, and protozoans, which become concentrated in filter-feeding organisms such as clams and oysters, making them unfit for human consumption.

Bacteria discharged with municipal wastewater are implicated in about half of the areas closed to shellfish harvesting along the Atlantic and Pacific coasts; the other half are closed because of non-point sources of bacteria (Indicators Task Force 1991). Between 1972 and 1993, the areas closed to shellfish harvesting because of fecal coliform bacteria increased along both coasts (Fig. 10.23). Shellfishery closures are legislated by the Department of Fisheries and Oceans, in association with Environment Canada; these departments conduct surveys of shellfish growing areas (the former department surveys the landed shellfish and the latter surveys the water where the shellfish are found) and make recommendations with respect to the safety of these areas for harvesting for human consumption.

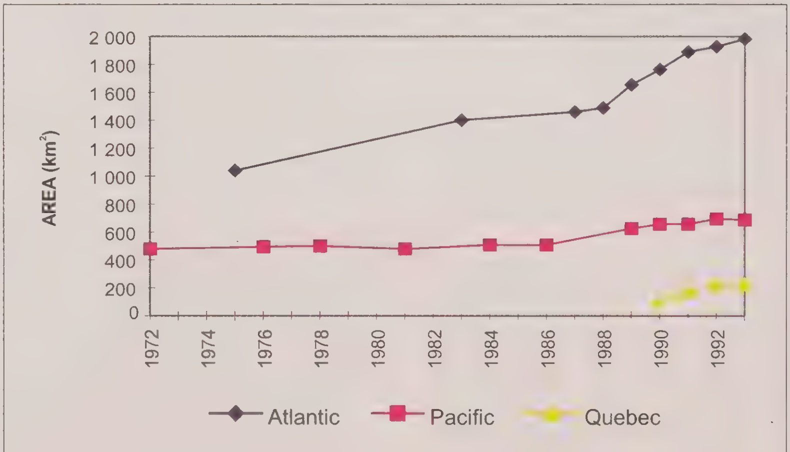
The problem of bacterial contamination of coastal areas through the disposal of inadequately treated municipal waste and releases from non-point sources is chronic. This problem will escalate with the continued development of coastal regions unless adequate wastewater treatment measures and reductions of non-point sources are undertaken to reflect increases in population and industry.

Ocean disposal

Environment Canada regulates the disposal of substances at sea and meets its international obligations under the London Convention (1972) by means of a system of permits under CEPA and the Ocean Dumping Regulations. Each application for disposal at sea is separately evaluated to determine if a permit will be issued. Disposal at sea is permitted only for nonhazardous substances and where it is the environmentally preferable and practical option. Permits are not granted if practical opportunities are available to recycle, reuse, or treat the waste.

On average, 174 permits were issued annually between 1983 and 1994 (Table 10.14). The number of permits issued declined in the last three years of this period, likely as a result of a moratorium on some cod stocks and a reduction in

Figure 10.23
Areas closed to shellfish harvesting because of fecal coliform contamination, 1972–1993



Source: Environment Canada (1996b).

capelin catch, which reduced the demand for fish waste disposal. Prior to this decline, the number of permits issued nationally had tended to increase, largely because of a significant rise in the number of permits issued for fisheries waste disposal in Atlantic Canada.

Between 1983 and 1994, an annual average of 7.8 million tonnes of material was covered by permits for ocean disposal. Dredged material typically accounts for 90% of the total, but the quantities are related to economic conditions: in the good times, large-scale dredging projects increase demand for disposal.

In November 1991, a $10 million Ocean Dumping Control Action Plan was initiated to develop improved regulations, enhance surveillance, and set up a national program to reduce persistent plastics. The first phase of regulatory amendments consisted of a revision of permit application fees and forms. The second phase consists of proposed new environmental assessment procedures and standards to better account for effects on the marine environment. Guidelines for marine sediment quality are being developed. Standard methods are also being developed for a battery of four toxicity tests to be conducted on species indigenous to the Canadian marine environment. These tests are designed to examine lethal and sublethal chronic effects and are required if the guideline limits for marine sediment quality are exceeded. Enhanced surveillance has been achieved by augmenting the monitoring of disposal sites. Since the onset of the action plan, Environment Canada personnel have monitored a total of 13 disposal sites; at 4 sites, permit holders have been required to provide data as a specific condition of their permit (Environment Canada 1995e). As part of this initiative, monitoring guidelines are progressively being developed, field tested, and phased in to routine monitoring.

Habitat degradation

The loss of marine habitat, especially coastal habitat, is a global problem that affects some of the most productive and diverse marine ecosystems in the world (Worldwatch Institute 1994). Marine habitat change and loss are, for the most part, undocumented in Canada. Although much is known about the impacts of megaprojects, the effects of day-to-day development activities are not being assessed. This lack of information about cumulative impacts is itself a threat to ensuring the sustainability of marine habitat.

Coastal development activities have the potential to affect the productivity of rich nursery and rearing environments for fish as well as ecologically important areas such as salt marshes and mudflats. Housing developments, dredging, and construction of dikes, wharves, piers, breakwaters, and causeways, as well as recreational activities, can all have significant impacts on habitat and may even reduce species diversity if not properly planned. Dragger fishing, harvesting of marine plants, and other ocean-based activities may also impact feeding and cover areas for a variety of ecologically and commercially important species (see the "Fisheries" segment of Chapter 11 for more details).

Ships commonly take on ballast water at one port of call and then release it at another port of call rather than in the open ocean. Canadian ports and coastal waters annually receive at least 52 million tonnes of discharged ballast water (Gauthier and Steel 1996). Uncontrolled dumping of ballast water at Canadian ports has introduced many nuisance exotic species into Canadian waters; continued dumping is likely to introduce additional species, with the potential to disrupt coastal ecosystems — through both habitat alterations and competition with native species. Ships can also affect the marine environment by releasing bilge water, sewage, chemicals, and garbage.

Table 10.14
Trends in ocean disposal permits issued and quantities permitted, 1983–1994

	Atlantic region		Pacific region		Quebec region		Northern region		National	
Year	Permits	Quantities (t, 000s)	Permits	Quantities (t, 000s)	Permits	Quantities (t, 000s)	Permits	Quantities (t, 000s)	Permits	Quantities (t, 000s)
1983	77	3 612	41	4 700	15	100	1	0	134	8 412
1984	84	3 310	33	4 000	17	100	5	800	139	8 210
1985	88	2 939	44	3 004	17	100	12	2 000	161	8 043
1986	96	3 023	42	3 404	20	100	10	1 700	168	8 227
1987	101	2 529	37	4 392	25	303	2	56	165	7 281
1988	81	3 254	48	4 532	28	400	2	100	159	8 286
1989	116	2 334	36	4 671	23	300	2	300	177	7 605
1990	131	2 256	31	5 840	35	346	3	300	200	8 743
1991	159	2 243	29	4 158	30	300	4	201	222	6 902
1992	152	1 404	29	4 590	36	1 100	2	1	219	7 094
1993	140	2 301	23	4 584	31	304	1	12	195	7 201
1994	106	3 095	23	4 057	19	202	1	0.05	149	7 354

Source: Environment Canada (1995d).

Some studies using remote sensing have been undertaken recently to assess the amount of habitat change in specific regions. For example, in British Columbia, Wilson et al. (1994) noted that the extent of habitats in the Fraser River estuary and lower river has changed markedly. For example, salt marshes have decreased in area by about 82%, and brackish marshes have increased by 100% (Hutchinson et al. 1989; see also Table 10.15).

Sustainability and Canada's marine ecosystems

Canada has implemented various environmental action plans to protect and manage marine resources and marine environmental quality. The federal departments of Fisheries and Oceans and Environment are spearheading government actions (Table 10.16). The new approaches use an integrated, more ecologically minded framework. Furthermore, it is now apparent that managing resources and marine environmental quality cannot be done in isolation; there is a need to cooperate at all orders of government and with the private sector to minimize conflicts arising from the use of marine waters.

In the fall of 1994, the Minister of Fisheries and Oceans announced *A vision for ocean management*, a document that is expected to lead to legislation to foster the stewardship of the oceans. The new ocean management regime is to be based on an ecological approach and development of an integrated management system for activities affecting oceans and coastal waters. The success of implementing this initiative will depend on the extent to which stakeholder cooperation can be achieved.

Region-specific action plans include the Fraser River Action Plan, the Atlantic Coastal Action Program, the St. Lawrence Vision 2000, and the Ocean Dumping Action Plan. Parks Canada has identified 29 marine natural regions, within which areas will be identified for protection. The Government of Canada is committed to establishing three additional national marine conservation areas in 1996, including Gwaii Haanas and the Saguenay–St. Lawrence. An additional three marine conservation areas are to be created by the year 2000.

Sustainable coastal zone management is another strategic plan. Here, the purpose is to foster well-designed economic development integrated with environmental protection and conservation. In 1994, for instance, the Province of Nova Scotia released a discussion paper called "Coastal 2000," which provides a framework for the sustainability of its coastal resources (Nova Scotia Department of the Environment 1994). Additional action is taking place on other coasts, as awareness of the need for strategic planning to minimize conflicts grows.

Also on the east coast, the Gulf of Maine Council on the Marine Environment was formed in 1989 through the cooperative efforts of three U.S. states, two Canadian provinces, and federal agencies of both countries. The goal of the council is to promote an ecosystem approach to resource management, to promote public awareness of the Gulf's riches, and to foster marine research. A Gulf of Maine Action Plan has been implemented with work on environmental monitoring, curbing marine debris, protecting special natural areas, identifying sources of water pollution, and cooperating with existing community organizations on key issues facing the Gulf. As part of the action plan, the Gulfwatch Project was implemented in 1991 to provide information on the status, trends, and sources of risks to the marine environment in the Gulf of Maine.

The National Oceanic and Atmospheric Administration's Strategic Environmental Assessment Division and the Atlantic Coastal Zone Information Steering Committee, representing federal, provincial, and private sector interests in Canada, have embarked on a joint effort with the U.S. government to develop strategic assessment tools and databases for the east coast of North America. The East Coast of North America Strategic Assessment Project provides a vehicle for the development of information products and the necessary processes to produce them. It is a multipartner endeavour that has reached out to a broad range of stakeholders, including provincial and state agencies, universities, working groups under the Gulf of Maine Council on the Marine Environment, and community groups. The focus of the offshore component is the development of a better understanding of the ecosystem of the continental shelf from Cape Breton to Cape Hatteras. The inshore component focuses on the concern over the continuing decline of shellfish production areas. The overall goal is to use shellfish beds as one indicator of the status of coastal resources.

In addition, Canada has acted through governmental and nongovernmental organizations to develop and ratify international conventions, foster bilateral and multilateral agreements, and participate in international research programs such as the World Ocean Circulation Experiment and the Joint Global Ocean Flux Study, which specifically deal with ocean climate studies. Other international efforts promote the conservation and protection of marine environmental quality in a broad context.

Table 10.15

Changes in the extent of habitats in the Fraser River estuary and lower river

Habitat	At turn of century (km^2)	Present (km^2)	Change (km^2)	Change (%)
Salt marsh	22	4	–18	–82
Brackish marsh	8	16	8	+100
Freshwater marsh	2	6	4	+200
Riparian: bog, meadow, etc.	645	Uncertain	Uncertain	>–50
Floodplain lake	36	0	–36	–100

Source: Levings and Thom (1994).

Table 10.16
Examples of federal and provincial acts related to marine environmental quality

Federal	
Environment Canada *Fisheries Act*, Section 36/37 (joint with DFO) *Canada Wildlife Act* *Migratory Birds Convention Act* *National Parks Act* *Canadian Environmental Protection Act* *Canada Water Act* *International River Improvements Act* *Hazardous Products Acts*	**Health Canada** *Canadian Environmental Protection Act* *Food and Drugs Act* *Migratory Birds Convention Act* **Natural Resources Canada** *Oil and Gas Production and Conservation Act* *Canada Petroleum Resources Act* *Resources and Technical Surveys Act*
Department of Indian Affairs and Northern Development *Oil and Gas Production and Conservation Act* *Canada Petroleum Resources Act* *Public Land Grants Act* *Arctic Waters Pollution Prevention Act* *Territorial Lands Act* **Transport Canada** *Canada Shipping Act* *Arctic Waters Pollution Prevention Act* *Navigable Waters Protection Act* *Transportation of Dangerous Goods Act* **Department of Fisheries and Oceans (DFO)** *Fisheries Act* *Coastal Fisheries Protection Act* *Fisheries Development Act* *Territorial Sea and Fishing Zones Act* *Fish Inspection Act*	**Recent federal policies/policy initiatives** Federal Environmental Quality Policy Framework (1986) DFO Fish Habitat Management Policy (1986) Energy/Environment Agreement (1986) Canadian Arctic Marine Conservation Strategy (1987) DFO Oceans Policy for Canada (1987) DFO Canada's Oceans (1987) Environment and Development: A Canadian Perspective (CIDA) (1987) Science Policy for Canada Enforcement and Compliance Policy (CEPA) (1988) Multi-Year Marine Science Plan (1988) Federal Marine Environmental Quality Management Framework (1990) Green Plan (1990) Federal Policy on Wetland Conservation (1992)
Provincial/territorial	
New Brunswick *Clean Environment Act* *Crown Lands Act* *Quarryable Substances Act* **Quebec** *Environmental Quality Act* **Newfoundland** *Provincial Affairs and Environment Act* *Waste Material (Disposal) Act* **Prince Edward Island** *Environmental Protection Act* *Water and Sewage Act* **Northwest Territories** Environmental Protection Ordinance	**Nova Scotia** *Beaches and Foreshores Act* *Beaches Act* *Environmental Protection Act* *Health Act* *Water Act* *Dangerous Goods and Hazardous Wastes Management Act* **British Columbia** *Environment and Land Use Act* *Water Act* *Health Act* *Environment Management Act* *Waste Management Act* *Utilities Commission Act*

Source: Department of Fisheries and Oceans and State of the Environment Directorate, Environment Canada.

For example, the 1982 United Nations Convention on the Law of the Sea (UNCLOS) gives a framework for the protection and preservation of the marine environment. UNCLOS also provides the legal framework for Canada's recent agreement to participate in a Global Programme of Action to Protect the Marine Environment from Land-Based Activities. The Global Programme of Action calls on countries to develop regional and national action programs to prevent, reduce, and control land-based activities that contribute to the degradation of the marine environment. In 1991, Canada and seven other countries adopted the Arctic Environmental Protection Strategy. This strategy commits the eight countries to cooperate to ensure the protection of the Arctic environment and its sustainable and equitable development.

Wildlife

More than fur and feathers

For many years, the term "wildlife" was almost synonymous with "mammals and birds," and for many people the word still elicits this meaning. As used in this chapter, however, and in the rest of this report, the term pertains to all wild, living things — all nondomesticated living organisms, as defined in the Wildlife Policy for Canada (Wildlife Ministers' Council of Canada 1990). It includes all plants, animals, and microorganisms of both terrestrial and aquatic (freshwater and marine) ecosystems.

The importance of wildlife

Many ecological processes depend upon wildlife. For example, bacteria, algae, fungi, trees, and invertebrate animals play powerful roles in such processes as photosynthesis, nitrogen fixation, nutrient cycling, waste decomposition, water purification, soil formation, and climate control. The health and abundance of all vertebrate species — mammals (including humans), birds, fish, amphibians, and reptiles — cannot be separated from the well-being of the invertebrates, plants, and microorganisms upon which they ultimately depend.

Viewed as a resource, wild species provide an enormous range of social and economic benefits. Many who follow traditional lifestyles continue to depend directly on wildlife as important sources of food, clothing, and income. The harvesting and processing of wild species produce a variety of commercial products, ranging from food and fashions to paper, construction materials, and medicines. In the case of medicines, many of the drugs sold in Canada were originally "discovered" in plants, although most are synthesized for the marketplace. For example, the active ingredient found in one of the world's most common medicines, acetylsalicylic acid (ASA or "aspirin"), was first detected in White Willow, a tree native to Europe and western Asia (Federal–Provincial–Territorial Biodiversity Working Group 1995). A similar compound was later isolated in Meadowsweet — a wild shrub common across much of southern Canada. More recently, the compound taxol, which is currently undergoing clinical testing as an anti-cancer drug in Canada and the United States, has been found in the bark and foliage of the Pacific Yew, a small coniferous tree that grows in British Columbia's coastal forests (Mosquin et al. 1995).

The economic value of Canada's flora and fauna is enormous. For example:

- In 1993, Canadian forest products generated $37.6 billion in total sales (see Chapter 11).
- The fur industry, which involves about 100 000 Canadians, including many Aboriginal trappers, contributes up to $1 billion annually to the economy.
- In 1993, the total value of production from Canadian fisheries was $2.9 billion (see Chapter 11).
- In 1991, 19 million Canadians and 2 million U.S. tourists took part in a wide range of wildlife-related recreational activities in Canada, such as bird-watching, fishing, and hunting. Participants spent $9 billion, which helped to maintain more than 200 000 jobs, contributing $11 billion to Canada's gross domestic product and generating $5 billion in government tax revenues (Filion et al. 1993, 1994).

Canada's wildlife population

Canada's wildlife population encompasses more than an estimated 138 000 species (see Table 10.17). The number of species known to exist includes about 4 000 vascular plants (about 3 000 of which are native to Canada), nearly 1 800 vertebrate animals, and more than 44 000 invertebrates.

The state of wildlife in Canada is continually in flux. Some of this change occurs naturally. Populations of many species of plants, animals, and microorganisms periodically undergo fluctuations owing to such factors as disease, weather events (floods, droughts, heavy snowfalls, temperature extremes, etc.), naturally occurring fires, competition among species, and predation.

Human activities also lead to changes. Through accidental or intentional introductions, nonnative species enter the country. Species may also disappear, either locally or nationally, or their populations may be reduced dramatically. Habitats may change through land use conversions, fragmentation, contamination by toxic chemicals, or other human activities. This section principally addresses these human-related changes.

The state of wildlife in Canada cannot be assessed in isolation from all the other main components of ecosystems. Achieving the goal of wildlife sustainability therefore requires consideration of the three ecological aspects of sustainability outlined in the World Conservation Strategy (IUCN et al. 1980) and the report of the World Commission on Environment and Development (1987):

- maintenance of life support systems;
- preservation of biodiversity; and
- maintenance of the productive capacity of species and ecosystems.

Habitat alterations

Habitat is the key to sustaining wildlife: without adequate and healthy habitat, wildlife cannot survive. A variety of human activities and natural phenomena are affecting habitats in Canada; the effects may be positive or negative, depending on the species or group of species being considered.

Physical changes

In 1992, 9 332 km^2 of forest were logged in Canada, mostly by clear-cutting (see Chapter 11). When an area is logged, the resulting change in forest age-classes represents a temporary loss or fragmentation of habitat for certain species but, at the same time, enhances habitat for others. Most of the area logged is replanted, direct seeded (whereby seeds are sown mechanically), or treated by various means to prepare it for planting or seeding or to encourage natural regeneration (see Chapter 11). These measures help to return the land to forest habitat conditions. Replanting and reseeding, however, are not likely to repro-

duce the original species mix and balance, at least not for significant periods of time. Selection of species for replanting or reseeding is generally based more upon the commercial preferences of the forest industry than on replacing the original composition of the forest. This results in simplified, even-aged forest ecosystems more like tree farms than like stable, naturally evolved habitats.

Forest, grassland, and wetland habitats in many parts of the country have been converted to agricultural lands. Over time, these open agricultural landscapes have become a habitat type unto themselves. Nevertheless, the original habitat balance has been distorted. In recent years, many previously farmed lands that were found to be marginal for agricultural purposes have been abandoned and allowed to return to their wild state. Other marginal agricultural lands have been more directly restored through a number of conservation programs, including the NAWMP.

Habitats are also converted from their original condition through a variety of other human activities. Large-scale developments such as urbanization, major hydroelectric facilities, multilane highways and other transportation infrastructure, and various industrial activities have obvious effects on wildlife habitats. The effects of small-scale developments are much more subtle and more difficult to ascertain. Placing a dam on a small stream, for example, or stabilizing water levels in a lake for recreational purposes can have devastating effects on some local populations and positive effects on others. Hiking, the use of off-road vehicles, and certain other recreational pursuits may seem environmentally benign because their effects are nearly invisible, but the result can be widespread damage. Small-scale damage to wildlife habitat can have serious impacts on wildlife populations already under stress. At least five nationally endangered plants face some threat from off-road vehicles and trampling (C. Maxwell, Canadian Wildlife Federation, personal communication). This damage, however, may be easier to halt, through education and awareness campaigns, than some large-scale threats.

Fire suppression has a different kind of effect on habitats. It deters the return to early or pioneer stages of natural succession, with implications for species reliant on young-growth forest, and it may change the species composition of the climax forest in the area.

Table 10.17

Summary of the diversity of wild species in Canada

Kingdom	Major subdivisions and common names	Estimated no. of species: Reported to date	Estimated no. of species: Suspected but not reported
Procaryotae	Bacteria, cyanobacteria (blue-green algae), chloroxybacteria	2 400	20 800
Protista	Algae, diatoms, protozoa	6 303	2 980
Eumycota (fungi)	Zoosporic fungi, mushrooms, rusts, smuts, lichens, etc.	11 800	3 831
Plantae	Mosses and liverworts	965	50
	Club mosses, horsetails, and ferns	141	11
	Conifers and kin	34	0
	Dicots and monocots[a]	3 864	75
Animalia	Molluscs (snails, bivalves, octopus, squid, etc.)	1 500	135
	Crustaceans (crabs, lobsters, shrimp, krill, etc.)	3 139	1 411
	Arachnids (spiders, mites, ticks, and kin)	3 275	7 731
	Insects	29 913	24 653
	Other invertebrates	6 444	4 417
	Sharks, bony fish, and lampreys	1 091	513
	Amphibians and reptiles	84	2
	Birds	426	0
	Mammals	194	0
Total		71 573	66 609

Note: Viruses also contribute to Canada's biological diversity. Almost 150 000 species are suspected to exist in the country, but only about 200 species have been reported to date.

[a] Of the dicots and monocots, about 77% (2 980) are native, and the rest are exotic. Dicots are a group of flowering plants that have two seed leaves. They include many herbaceous plants and most families of trees and shrubs. Monocots are flowering plants with a single seed leaf, including grasses and lilies.

Source: Condensed from Mosquin et al. (1995).

Fragmentation

These and other human activities also result in varying degrees of habitat fragmentation. In the case of some animal species, individuals can become cut off from usable portions of their range. For example, many are reluctant to cross extensive open areas or physical barriers such as divided highways; those that make the attempt expose themselves to greater threats of predation and mortality.

Chemical changes

Even without direct conversion to other uses, terrestrial and aquatic habitats can be degraded by hydrocarbon spills, industrial and municipal effluents, and applications of pesticides and other chemical compounds. They can also be damaged by acidic deposition — the environmental acidification, particularly in eastern Canada, that results from the long-range transport of atmospheric pollutants (see the "Atmosphere" and "Fresh water" segments of this chapter). Such acidification can seriously degrade life support systems and reduce the overall productive capacity of ecosystems. On the other hand, some chemical alterations (e.g., increases in nitrogen and phosphorus) can enhance life support systems for certain species, thereby increasing the overall productive

capacity of ecosystems. (In the case of eutrophication, however, this increase in nutrients is self-defeating: the result is an oversupply of nutrients in lakes, rivers, and wetlands, to the detriment of ecosystem functioning.)

Climate change

Climate change has the potential to lead to dramatic alterations in the structure of ecosystems over the long term. Some species could find the evolving conditions favourable, whereas others, especially populations at the extremes of their ranges, could find them unsuitable and disappear. For example, climate change could possibly occur rapidly relative to the speed at which tree species of the boreal forest grow and reestablish themselves. As a result of global warming over the next 100 years, the current boreal climate and associated plants and animals could shift northward a considerable distance, whereas the present area of much of the boreal forest could take on some characteristics of the ecosystems currently located to the south of them (e.g., see Chapter 5).

Climate change could result in a shift in the location of many wildlife habitats. Coastal wetlands could be displaced or created as a result of rising sea level, or aquatic and semiaquatic habitats may recede as wetlands dry up and become more favourable to terrestrial species. The relative stability of all ecosystems is possibly at risk — at least in terms of human time frames and perceptions.

Box 10.4
With all the best intentions

Shakespeare's birds: an introduction to a North American audience

In the late 1800s, a wealthy American thought that it would be wonderful if the United States had populations of each of the bird species that Shakespeare mentioned in his works. Starlings, nightingales, skylarks, and a variety of other birds were brought to New York and released in Central Park (Rich 1993). One of these birds, the European Starling, had spectacular success. Introduced in 1890, the original 60 European Starlings have multiplied to more than 200 million today (Rich 1993). The bird has spread throughout North America, providing strong competition for the continent's native bird population. The species is now considered a pest in many areas. During the breeding season, the European Starling aggressively displaces native species that require holes in trees or other cavities for nest sites. These include House Wrens, bluebirds, several species of woodpeckers, House Finches, American Kestrels, and Tree Swallows. Furthermore, unlike most native birds, the European Starling is immune to the toxic fruits of the Glossy Buckthorn — an invasive exotic plant (see Table 10.18). In some areas, the bird acts as a principal carrier of the seed of this unwanted European shrub.

The menace behind the mask

In 1940, eight Raccoons were released on British Columbia's Queen Charlotte Islands to provide local trappers with a new species to harvest. Twelve species of seabirds, numbering roughly 1.5 million, have traditionally nested on the islands every summer, including storm-petrels, Pigeon Guillemots, Cassin's Auklets, and about three-quarters of the world's population of Ancient Murrelets, a species designated as vulnerable by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Most nest on the ground or in burrows and, in the absence of native mammalian predators, were historically safe from predation. Now, however, populations are declining at an alarming rate, and Raccoons are clearly to blame (Backhouse 1994).

Between 1985 and 1989, Raccoons destroyed or seriously damaged seabird colonies on East and West Limestone, Helgesen, and Saunders islands of the Queen Charlottes, killing or displacing 40 000–50 000 seabirds, which represent a potential loss of 10% of the breeding colonies of burrow-nesting alcids (e.g., Cassin's Auklets, Pigeon Guillemots, and Ancient Murrelets) on the Queen Charlotte Islands in only five years. Recently, on East Limestone Island, 3 Raccoons killed about 250 birds within a few weeks and dug up many nest burrows, consuming both eggs and chicks. Raccoons can readily swim across a kilometre or more of open water, putting seabird colonies on outlying islands at risk. Raccoons may never be completely eliminated from the Queen Charlotte Islands — the main hope lies in persistent monitoring and quick removal of Raccoons on islands that they invade (G. Kaiser, Canadian Wildlife Service, Environment Canada, Pacific and Yukon Region, personal communication).

Competition from nonnative biota

Alternatively known as alien, exotic, nonindigenous, or introduced, nonnative biota can become established in Canada by a variety of intentional or accidental means, sometimes leading to unforeseen effects (see Box 10.4). Native species are compelled to compete with nonnative species for space, water, food, and other essentials of life (e.g., see Table 10.18).

The total number of nonnative species is difficult to estimate. For example, many bacteria, algae, insects, earthworms, centipedes, and others were almost certainly introduced, but direct evidence is lacking (Mosquin et al. 1995). Among flowering plants, at least 884 species (about 23% of the wild flora) are known to be exotic (Scoggan 1978–1979, cited in Mosquin et al. 1995), and this number has increased since the tally was taken in the late 1970s. Most of these nonnative plants are "weeds," typically found in disturbed habitats, such as roadsides, construction sites, and farm fields. Among fishes, 11 (about 1%) of the reported species are exotic (McAllister 1990, cited in Mosquin et al. 1995).

Harvesting

Regardless of the type of wildlife harvested or the methods employed, harvesting has the potential to cause short- and long-term changes in populations and species composition. For example, logging causes at least a temporary reduction in tree populations, which affects the trees' delivery of

Table 10.18

Introduced, nondomesticated species that have had a major impact on the structure and functioning of Canada's ecosystems

Species	Year introduced	Nature of effect on other species and/or ecosystems
Fungi		
Blight, Chestnut	About 1900 from China	Virtually extirpated the American Chestnut as seed-reproducing tree in all of its range.
Ophiostoma ulmi[a]	1944 at Saint-Ours, Quebec (from Europe via United States)	Caused an enormous loss of the American Elm, especially in forests and swamps. Isolated elm survive in open farm country. Fungus is transmitted by elm bark beetles.
Plants		
Birch, European	Unknown	Cultivar; invades natural bog ecosystems.
Brome, Smooth	Between 1875 and 1888 (used as forage and for erosion control)	Suppresses and displaces native species in native prairie grasslands in western Canada; persists in roadsides and open areas across Canada, preventing the colonization of these areas by native species.
Broom, Scotch	1800s	Replaces native flora; major competitor for moisture in dry sites of southwest British Columbia.
Buckthorn, Common	Unknown	A large shrub or small tree that principally invades upland sites; displaces native species by the dense shade produced by its stands.
Buckthorn, Glossy	Unknown	Invades wetlands and some upland sites and displaces native species by the dense shade produced by its stands. It may also be allelopathic (i.e., repress or destroy other plants by releasing toxic substances).
Chess, Downy	1600s	Aggressively replaces native grasses and forbs in dry regions of the prairies and southern British Columbia; introduced by the Spanish into Mexico and then spread north.
Frog-bit, European	1932 (intentionally to aquatic environment at the Arboretum of the Central Experimental Farm in Ottawa)	Forms dense, floating mats on the surface of marshes and other wetlands, thus shading out submerged aquatic vegetation and restricting their access to dissolved gases and nutrients.
Grass, *Agropyron desertorum*	Unknown	This Asian grass replaces native species in native grasslands; planted by ranchers.
Grass, *Elymus junceus*	Unknown	This Asian grass replaces native species in native grasslands; planted by ranchers.
Loosestrife, Purple	Mid-1800s to early 1900s (from Eurasia)	Has a prolific seed production and aggressively replaces many marsh, swamp, and wet meadow species; forms pure stands.
Spurge, Leafy	Late 1800s, early 1900s	Aggressive herb principally invading open upland habitats such as native prairies, open woods, rangelands, agricultural lands, and roadsides; outcompetes most native herbs and considered serious threat to species at risk, such as the Western Spiderwort.
Watermilfoil, Eurasian	Date unclear, but most likely in the 1940s	Grows very quickly, particularly invading eutrophic waters, and creates dense submergent growth that displaces many native submergents.
Wheatgrass, Crested	Deliberate introduction by governments in 1915 from Siberia	Aggressively competes with native species in southern Prairie provinces. Major problem in Grasslands National Park.
Invertebrates		
Moth, Gypsy	From Europe into Massachussetts about 1868	Defoliates large tracts of forests in peak years.
Mussel, Zebra	1980s (introduced by the discharge of ballast water)	Southern Ontario and Quebec waterways: occupies large areas of underwater habitat and displaces native species of clams; its filter-feeding efficiency reduces the amount of plankton available to native filter feeders and larval fishes; significantly affects light penetration and abundance of submergents in lakes and rivers.
Nematode, Golden	Unknown	Herbivore pest in many plants; decimated potato crops on Vancouver Island and in Newfoundland.

continued on next page

Table 10.18 (continued)

Introduced, nondomesticated species that have had a major impact on the structure and functioning of Canada's ecosystems

Species	Year introduced	Nature of effect on other species and/or ecosystems
Fishes		
Carp, Common	1880	Muddies up marshes; destroys submergent vegetation, food, and cover.
Lamprey, Sea	1921 (introduced by the discharge of ballast water)	Parasite; killed large numbers of fishes following entry to upper Great Lakes through Welland Canal.
Birds		
Sparrow, House	1850	Usurps nesting cavities for bluebirds, woodpeckers, swallows, etc.
Starling, European	1890	Usurps nesting cavities for bluebirds, woodpeckers, swallows, etc.
Mammals		
Deer, Mule	1900–1916	Queen Charlotte Islands: overgrazes forest ecosystems and selectively impairs regeneration of shrubs and key tree species.
Horse	1600s	Sable Island, Nova Scotia: Major destruction of native vegetation cover, accelerating wind erosion of sand dunes, impacting on many species (e.g., the Ipswich Sparrow).
Raccoon	1940s	Queen Charlotte Islands: competes aggressively for food in intertidal zone; raids seabird colonies.
Rat, Norway	1775	Naturalized on bird islands and shorelines of Atlantic and Pacific (e.g., Queen Charlotte Islands); destroys nests and eggs of colonial seabirds.

[a] The causal agent of Dutch elm disease.

Source: Mills et al. (1993); White et al. (1993); Mosquin et al. (1995).

ecological functions such as habitat provision, carbon fixation, and oxygen production. Logging also affects the structure of the forest community, typically by removing older-growth stands and replacing them with younger trees.

Harvesting also represents enormous extractions from the population pools of aquatic species. For example, in 1993, Canadian commercial landings of fish amounted to 1 145 679 t (see Chapter 11). The structures of fish populations and of ecosystems are affected, as harvesting of fish intentionally targets larger (and usually older) specimens.

Small-scale harvesting also cannot be overlooked, especially in the case of species already at risk. For example, at least nine nationally endangered plants face some threat from collection (C. Maxwell, Canadian Wildlife Federation, personal communication).

Toxic contaminants in the environment

Toxic substances may occur naturally in the environment. The mercury and lead found in bedrock and soils are two examples. They may also be anthropogenic, entering ecosystems by industrial discharges, municipal wastes, agricultural and forestry activities, and many other pathways and dispersing over great distances in air and water currents. Chapter 13 provides information on these pathways of dispersal as well as on some of the effects of toxic substances on organisms.

The following briefly examines two notable groups of toxic substances: persistent organochlorines and metals.

Persistent organochlorines[1]

Organochlorines are a family of chemicals that include various pesticides, industrial chemicals, and by-products of certain industrial processes. Some organochlorines can take decades or even centuries to break down naturally, which is why they are termed persistent. Because of this persistence and their high solubility in fat, they tend to accumulate in the tissues of some animals (bioaccumulation). They are then passed through food webs and can reach very high concentrations in the tissues of predators at the top (biomagnification).

Concerns about the effects of persistent organochlorines on wildlife and humans arose in the early 1960s. Since then, regulations have been adopted in North America to ban the use of many of these compounds or severely restrict their release into ecosystems. Certain wildlife species are often used as environmental indicators to monitor levels of these toxic contaminants in ecosystems (see Box 10.5). One of these indicator species is the Double-crested Cormorant. Researchers are able to monitor concentrations of selected compounds in this species' eggs.

1. The section on persistent organochlorines has been extracted from Environment Canada (1993d).

The insecticide DDT was widely used in Canada between 1947 and 1969 to control agricultural and forest insects. The main breakdown product of DDT is dichlorodiphenyldichloroethylene (DDE), a compound that interferes with enzymes necessary for the production of calcium carbonate in female Double-crested Cormorants and other birds. Eggshells with less calcium carbonate are thinner and more likely to crack or break during incubation. Because of these and other toxic properties, most uses of DDT were banned in Canada by the mid-1970s. Concentrations of DDE have declined substantially since the 1970s (see Fig. 10.24). In recent years, declines have levelled off, possibly as a result of the slow release of contaminant residues from bottom sediments or long-range atmospheric transport from countries still using DDT.

PCBs are a group of organochlorines that were imported into Canada for such uses as insulating fluids in electrical equipment, flame retardants, and lubricants. Further importation and most nonelectrical uses were banned in 1977. PCBs have been linked to bill defects in Double-crested Cormorant chicks (Fox et al. 1991). Levels of PCBs in Double-crested Cormorant eggs have declined, but the declines have been inconsistent (see Fig. 10.24). This may be due to the release of PCBs still in use, the escape of PCBs from storage and dump sites, ongoing cycling in the environment because of their long life, or the long-range transport of PCBs from other countries.

Although concentrations of persistent organochlorines in wildlife have declined significantly in Canada since the early 1970s, the contaminants have not disappeared. As discussed in Box 7.1 in Chapter 7, persistent organochlorines are implicated in declines in seabird populations in the Gulf of St. Lawrence.

Box 10.5
The use of wildlife indicators to track toxic contaminants in ecosystems

Indicators are selected key statistics that represent or summarize some aspect of the state of ecosystems. By focusing on trends in environmental change, they convey how ecosystems are responding to both stresses and management responses.

Certain toxic organochlorines, including DDE, PCBs, and some dioxins and furans, have been monitored in species of wildlife since the early 1970s. Tracking concentrations in wildlife simplifies the detection of some chemicals that are present in extremely low concentrations in air and water and are therefore difficult to measure directly. Levels of some organochlorine contaminants in the eggs of fish-eating birds, for example, may be as much as 25 million times the concentrations in the waters in which the fish live, because of the processes of bioaccumulation and biomagnification.

The Double-crested Cormorant has been selected as a national indicator species for organochlorine levels in wildlife because of its broad distribution across southern Canada, especially in areas of concentrated human activity, and because it is a top predator that eats live fish. A disadvantage of using the Double-crested Cormorant as an indicator, however, is that, like many Canadian birds, it migrates south in the winter. It is therefore not known what proportion of the contaminants measured in its eggs comes from non-Canadian sources.

Metals[2]

Metals occur naturally within the Earth's crust. In trace amounts, many metals, such as magnesium and zinc, are essential to both plant and animal life. Other metals, such as mercury and lead, do not appear to have a nutritional or biochemical function. As discussed in the "Oceans" section of this chapter, the presence of these elements in low concentrations does not normally give rise to any toxic effects, but at higher concentrations, they can have adverse effects on plant or animal growth and health.

Mercury

Mercury is a widespread, naturally occurring element, generally found at low concentrations in the environment. In 1956, the toxicity of mercury attracted worldwide attention when extensive mercury poisoning was discovered in the Japanese fishing village of Minamata (see Chapter 13). Over the next 20 years, 107 deaths and several hundred cases involving serious sublethal effects, including brain damage and birth defects, were reported. The outbreak resulted from the eating of fish and shellfish contaminated by methylmercury chloride effluent from a nearby chemical plant.

In Canada, industrial sources of mercury to the environment have nearly disappeared. Inorganic mercury is not thought to cause adverse effects in wildlife, but mercury in the form of methylmercury does have toxic effects. In the late 1970s, a link was established between flooding for hydroelectric development and mercury contamination. The naturally occurring inorganic mercury in the submerged organic material is converted into methylmercury by bacteria that thrive in the absence of dissolved oxygen at the bottom of reservoirs. Mercury also can be transported long distances through the atmosphere.

Methylmercury bioaccumulates readily in many organisms and also biomagnifies throughout food webs. Fish-eating predators (e.g., American Mink, River Otter, seals, Osprey, Bald Eagle, and Common Loon) are particularly susceptible. Elevated methylmercury levels in fish have led to advisories about human consumption of fish above certain sizes from both reservoirs and natural lakes. The longer — and therefore the older — the fish, the more mercury it is likely to have accumulated. Methylmercury destroys brain cells in wildlife and humans, and characteristic symptoms of methylmercury poisoning include vision problems and an inability to coordinate muscle movements.

Lead

The use of lead in hunting ammunition has traditionally been popular. An average shotgun shell used for waterfowl hunting contains several hundred lead pellets, most of which do not hit the bird but fall

2. Except where noted otherwise, the section on metals has been extracted from Sinclair (1994, 1995).

into the water or onto land. Waterfowl typically are hunted in areas where the birds stop to rest and feed. Lead shot ingestion is probably the primary source of lead poisoning in Canadian waterfowl and most other bird species (Scheuhammer and Norris 1995). Ducks feeding on the bottom of lakes, rivers, and wetlands can readily ingest the lead pellets. These then enter the gizzard, where granular materials are often retained to help grind the bird's food. Here, the lead becomes available for absorption into the body.

Secondary lead poisoning is an additional consideration. For example, cases of lead poisoning in Bald Eagles have been attributed to feeding on waterfowl carrying lead pellets embedded in their bodies. Studies in Canada and the United States have estimated that lead poisoning resulting from eating prey with lead shot embedded in their tissues or gizzards accounts for 10–15% of the postfledging mortality of Bald and Golden eagles (Scheuhammer and Norris 1995). In Canada, several provinces and territories are committed to phasing out the use of lead shot for waterfowl hunting. Moreover, there will be a national ban on the use of lead shot for all migratory game bird hunting beginning in 1997 (Scheuhammer and Norris 1995). In 1995, British Columbia became the first province to ban the use of lead shot for hunting waterfowl (the ban does not include target shooting or game bird hunting in upland areas, however).

Secondary lead poisoning can also be a threat to wildlife as a result of recreational fishing. Fish often escape anglers with "hook, line, and sinker" still intact. Loons or other fish-eating birds may then catch these fish and swallow them whole and then themselves develop lead toxicosis (see Fig. 10.25). A number of nontoxic substitutes for lead sinkers are currently on the market. However, the potential for

Figure 10.24
Concentrations of DDE and PCBs in Double-crested Cormorant eggs, 1970–1993

Note: In parts per million (mg/kg wet weight), based on arithmetic means, for years data available (i.e., sampling is not carried out annually).

Source: Environment Canada (1993c); 1993 data for Strait of Georgia from Canadian Wildlife Service, Environment Canada.

impacts from substitutes on wildlife has not yet been thoroughly reviewed.

Cumulative agents of change

Although wildlife change can be driven by a single factor, more commonly a combination of elements is involved. Some of these are direct and evident, whereas others are far less apparent and affect the situation more indirectly. Box 10.6 provides an example by looking at a poorly appreciated group of wildlife — insects. It illustrates how wildlife populations can become reduced as a result of habitat loss, the application of pesticides, and other factors. It also demonstrates a type of "domino effect" in total ecosystem functioning and some ecological and economic implications of these changes.

A few indications of change

Wildlife at risk

One measure of change in the status of Canada's native wildlife is to monitor the condition of those that are recognized as being at risk of eventual extinction. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) annually assesses Canada's native mammals, birds, fish, reptiles, amphibians, and plants and assigns levels of susceptibility. As of 1995, COSEWIC had assigned status to 263 species, subspecies, or populations of native wild animals and plants. Of these, 243 are currently listed as endangered, threatened, or vulnerable, another 11 are considered extirpated, and 9 are extinct. A further 87 had been considered and found to require no designation at the time, and 10 more were examined and not designated in any risk category because of insufficient scientific information.

The COSEWIC list is not itself a definitive measure of species that are at risk in Canada. It does identify many species that are known to be at risk and regions of the country where they are at risk. However, at present, the numbers represent only those "higher-order" species whose status has been reviewed so far; the actual number at risk is undoubtedly considerably higher. COSEWIC is now beginning to research and review the status of other species groups, including invertebrates such as molluscs (snails, clams, etc.) and the lepidopteran order of insects (butterflies and moths). There is a general lack of information on most invertebrate species, which makes it very difficult to produce status reports on them. Therefore, COSEWIC is limited to dealing with the small number of invertebrates for which there is some information available. Other invertebrates will be added as it becomes practical.

Table 10.19 provides a national summary of species, subspecies, and populations of all types of wildlife listed by COSEWIC as endangered or threatened. The table also gives a rough indication of the locations in which they occur. Table 10.20 shows how many of each of these categories are found in each of Canada's provinces and territories and in each of the country's terrestrial and marine ecozones.

Figure 10.25
X-ray of lead sinker in digestive tract of Common Loon that died from lead toxicosis

Photo credit: Kit Chubb, Avian Care and Research Foundation, Verona, Ontario.

Population changes

Another way to measure whether the situation is improving or deteriorating for native wildlife in Canada is to chart long-term population trends. However, few programs currently exist to provide this kind of information. Following is some national trend information for birds, based upon a number of programs that have been functioning over the long term.

Populations of breeding songbirds often show large year-to-year fluctuations, so long-term data on population change are essential. This type of data is scarce, although a number of population monitoring programs do focus on songbirds in Canada and the United States. These include the Breeding Bird Survey, the Christmas Bird Count, and Migration Monitoring Stations. The annual Breeding Bird Survey has been conducted each spring since 1966 along about 3 000 routes throughout the United States and Canada by a network of skilled amateur and professional ornithologists (Downes and Collins 1996). Most of Canada's roughly 420 routes are located in the southern part of the provinces. A few routes in Yukon and the Northwest Territories are now being run, but the data are too recent to show long-term trends. Population trends for species characterized by particular migration patterns (long-distance migrants, short-distance migrants, and residents or nonmigrants) and habitat types (forest, scrubland, and grassland) were determined for Canada as a whole as well as for each of seven terrestrial ecozones (Table 10.21).

Not all of the numbers indicated in Table 10.21 are statistically significant, but several trends are nonetheless apparent. For example, bird populations declined in grassland habitats in six of the seven ecozones. For forest habitats, five ecozones showed population increases and only the Pacific Maritime showed a decrease. Scrubland habitats showed mixed trends — three ecozones showed population increases and four showed decreases. An important consideration regarding the methods used is that analysis based upon habitat type combines many individual species that may have very specific requirements — some may be doing well, whereas others are not (C. Downes, Canadian Wildlife Service, Environment Canada, personal communication). Further, populations in particular habitat types may show large year-to-year fluctuations in any ecozone. Habitat analysis is intended only as a rough examination of what is going on, rather than a final assessment. Particular species must be examined to develop a more complete picture.

Analyses based upon migration patterns indicated that short-distance migrants had declines in six ecozones, with two of the declines being significant; the trends for residents and long-distance migrants were less clear, with a mixture of increases and decreases in various ecozones. Analyses for the country as a whole revealed that the grassland and scrubland habitat and

Box 10.6
Caution: pollinators at work

People tend to overlook the value of insects. For example, even though Canada produces about $49 million worth of honey each year and consistently ranks among the top five honey exporters in the world, many Canadians associate bees with their nasty sting more than with their honey production. And honey is not the only value of bees that tends to be underestimated.

For flowering plants, pollination is a vital step in sexual reproduction. Further, cross-pollination — the transfer of pollen from one plant to the seed-bearing body of a similar plant — serves to increase genetic diversity. Although wind and other means help some plants to pollinate, insects greatly increase the success rate and in some cases are the only means. Agriculture and Agri-Food Canada has estimated that pollinators, most of which are insects, contribute more than $1 billion annually to Canadian agriculture through the pollination of apples, strawberries, Alfalfa, clover, and other crops. In recent decades, however, declines in populations of several of the country's important pollinators have been linked to human activities.

In 1970, in an effort to control Spruce Budworm and support the province's forest industry, New Brunswick began using the insecticide fenitrothion. Populations of native wild bees subsequently plummeted. Similar declines in populations of native bees have also been noticed in areas of Ontario and Quebec where fenitrothion has been used.

The use of pesticides in agricultural regions can also affect populations of pollinators. Insecticides aimed at killing particular insects can also kill nontargeted pollinators in the sprayed area. Pollinators can also be affected more indirectly by the application of herbicides to control plants that are commonly considered weeds, such as Common Milkweed, Canada Thistle, and Chicory. These plants are often excellent sources of nectar and pollen.

Habitat change is another obstacle faced by pollinators in agricultural regions. Vast fields of monoculture crops do not provide the variety of mating, nesting, and foraging habitats required by most pollinators.

The Monarch Butterfly is one insect pollinator that is highly valued by humans for aesthetic reasons. In its larval life stage, this species relies exclusively on Common Milkweed. Common Milkweed is currently on the noxious weed list of all Canadian provincial jurisdictions; however, this has had no demonstrated impact on either the plant or the pollinator. Threats to the Monarch Butterfly have arisen from habitat change on its wintering grounds in Mexico. Recognizing the need to act jointly to protect the Monarch Butterfly and its critical seasonal habitats, Canada and Mexico signed a declaration in October 1995 to nominate sites as part of an international network of Monarch Butterfly reserves. For Canada, the sites declared to date are Long Point National Wildlife Area, Point Pelee National Park, and Prince Edward Point National Wildlife Area, all of which are in Ontario.

Source: Kingsmill (1993); Canada–Mexico (1995).

Table 10.19

Status and geographic location of endangered and threatened species, subspecies, and populations in Canada, 1995

Species group	Status and geographic location					
	Endangered	Province/ territory	Ecozone[a]	Threatened	Province/ territory	Ecozone[a]
Mammals	Caribou, Peary Banks Island population High Arctic population	 NT NT	 NA AC, NA	Bison, Wood	AB, BC, NT, YT	TP, BP, BC
	Cougar (eastern population)	NB, NS, ON, QC	AM, BS, MP	Caribou, Peary (low Arctic population)	NT	NA, SA
	Marmot, Vancouver Island	BC	PM	Caribou, Woodland (Gaspé population)	QC	AM
	Otter, Sea (Pacific coast)	BC	PM	Marten (Newfoundland population)	NF	BS
	Whale, Bowhead eastern Arctic population western Arctic population	 NT, QC YT, NT	 AA AA	Porpoise, Harbour (northwest Atlantic population)	QC, NB, NF, NS, PE	AN, AO
	Whale, Right (Pacific and Atlantic oceans)	BC, NF, NS, QC	PO, AN, AO	Shrew, Pacific Water	BC	PO, PM
	Whale, White (Beluga) St. Lawrence River population Southeast Baffin Island–Cumberland Sound population Ungava Bay population	 QC NT NT, QC	 AO AA AN	Whale, Humpback (North Pacific population)	BC	PO
	Wolverine (eastern population)	NF (Labrador), QC	AC, NA, SA, TS, BS	Whale, White (Beluga) (eastern Hudson Bay population)	QC	AA
Birds	Bobwhite, Northern	ON	MP	Chat, Yellow-breasted (B.C. population)	BC	MC
	Crane, Whooping	NT	TP	Murrelet, Marbled	BC	PM
	Curlew, Eskimo	NT	SA	Shrike, Loggerhead (Prairie population)	AB, MB, SK	BP, PR, BS
	Duck, Harlequin (eastern population)	NB, NF, NS, QC	AC, NA, SA, TS, AM, BS	Sparrow, Baird's	AB, MB, SK	PR
	Falcon, Anatum Peregrine	AB, BC, MB, NB, NF, NS, SK, YT	TP, TS, BS, AM, MP, BP, PR, TC	Tern, Roseate	NS, QC	AM
	Flycatcher, Acadian	ON	MP	Warbler, Hooded	ON	MP
	Owl, Burrowing	AB, BC, MB, SK	BS, PR, BP, MC	Woodpecker, White-headed	BC	MC
	Owl, Spotted	BC	PM, MC			
	Plover, Mountain	AB, SK	PR			
	Plover, Piping	AB, MB, NB, NF, NS, ON, PE, QC, SK	BP, BS, PR, AM, MP			
	Rail, King	ON	MP			
	Shrike, Loggerhead (eastern population)	MB, ON, QC	MP, BS, AM			
	Sparrow, Henslow's	ON, QC	MP, BS			
	Thrasher, Sage	AB, BC, SK	MC, PR			
	Warbler, Kirtland's	ON	MP			
Amphibians	Frog, Blanchard's Cricket	ON	MP			
Reptiles	Snake, Blue Racer	ON	MP	Rattlesnake, Eastern Massasauga	ON	BS, MP
	Snake, Lake Erie Water	ON	MP	Turtle, Blanding's (Nova Scotia population)	NS	AM
	Turtle, Leatherback	BC, NS, NF	PO, AN, AO	Turtle, Spiny Softshell	ON, QC	MP

continued on next page

short-distance migrant groups showed significant declines, and only the forest habitat group showed an overall increasing population.

The reasons for changes in bird numbers are not completely understood, although loss and fragmentation of habitat (as forests and grasslands are urbanized or converted to cropland), pesticide use, climate change, severe weather events, and competition from other species may all figure in the changes. These types of influences occur in wintering grounds in the United States and Central and South America as well as in Canada.

The high position of raptors (birds of prey) in food webs makes them ideal indicators of overall environmental health (Oliphant 1995). If the environment is healthy enough to support viable populations of these top carnivores, the rest of the ecosystem can probably be assumed to be healthy as well. For instance, population

Table 10.19 (continued)

Status and geographic location of endangered and threatened species, subspecies, and populations in Canada, 1995

Species group	Status and geographic location					
	Endangered	Province/ territory	Ecozone[a]	Threatened	Province/ territory	Ecozone[a]
Fish	Sucker, Salish	BC	PM	Cisco, Blackfin	ON	BS, MP
	Trout, Aurora	ON	BS	Cisco, Shortjaw	AB, MB, NT, ON, SK	TS, BS, MP, HP
	Whitefish, Acadian	NS	AM			
				Cisco, Shortnose	ON	BS, MP
				Darter, Channel	ON, QC	BS, MP
				Darter, Eastern Sand	ON, QC	BS, MP
				Madtom, Margined	ON, QC	MP
				Redhorse, Black	ON	MP
				Redhorse, Copper	QC	MP
				Sculpin, Great Lakes Deepwater	AB, MB, NT, ON, QC, SK	MP, TP, TS, BS, BP
				Sculpin, Shorthead	BC	MC
				Stickleback, Enos Lake	BC	PM
				Whitefish, Lake Simcoe	ON	MP
Plants	Agalinis, Gattinger's	ON	MP	Ash, Blue	ON	MP
	Agalinis, Skinner's	ON	MP	Aster, Anticosti	NB, QC	AM, BS, TS
	Cactus, Eastern Prickly Pear	ON	MP	Aster, White Wood	ON, QC	MP
	Clover, Slender Bush	ON	MP	Bluehearts	ON	MP
	Coreopsis, Pink	NS	AM	Chestnut, American	ON	MP
	Fern, Southern Maidenhair	BC	MC	Colicroot	ON	MP
	Gentian, White Prairie	ON	MP	Deerberry	ON	MP
	Lady's Slipper, Small White	MB, ON	MP, PR, BP	Fern, Mosquito	BC	MC
	Lousewort, Furbish's	NB	AM	Flag, Western Blue	AB, BC	MC, PM, PR
	Milkwort, Pink	ON	MP	Gentian, Plymouth	NS	AM
	Mint, Hoary Mountain	ON	MP	Ginseng, American	ON, QC	BS, MP
	Mountain Avens, Eastern	NS	AM	Golden Crest	NS	AM
	Mouse-ear-cress, Slender	AB, SK	PR	Golden Seal	ON	MP
	Orchid, Western Prairie White Fringed	MB	PR	Greenbrier, Carolinean	ON	MP
	Plantain, Heart-leaved	ON	MP	Helleborine, Giant	BC	MC
	Pogonia, Large Whorled	ON	MP	Jacob's Ladder, van Brunt's	QC	MP
	Pogonia, Small Whorled	ON	MP	Lipocarpha, Small-flowered	BC, ON	MP, MC
	Poppy, Wood	ON	MP	Mulberry, Red	ON	MP
	Quillwort, Engelmann's	ON	BS	Paintbrush, Golden	BC	PM
	Sundew, Thread-leaved	NS	AM	Pepperbush, Sweet	NS	AM
	Tree, Cucumber	ON	MP	Pogonia, Nodding	ON	MP
	Water-pennywort	NS	AM	Redroot	NS	AM
	Wintergreen, Spotted	ON	MP	Spiderwort, Western	AB, MB	PR
				Thistle, Pitcher's	ON	BS, MP
				Thrift, Athabasca	SK	BS
				Tree, Kentucky Coffee	ON	MP
				Twayblade, Purple	ON	MP
				Verbena, Sand	AB, SK	PR
				Violet, Bird's-foot	ON	MP
				Violet, Yellow Montane	BC	PM
				Water-willow, American	ON, QC	MP
				Willow, Tyrrell's	SK	BS
				Woodsia, Blunt-lobed	ON, QC	MP, BS

[a]Ecozone legend:

Terrestrial ecozones	Codes
Pacific Maritime	PM
Montane Cordillera	MC
Boreal Cordillera	BC
Taiga Cordillera	TC
Prairies	PR
Boreal Plains	BP
Boreal Shield	BS
Mixedwood Plains	MP
Atlantic Maritime	AM
Taiga Plains	TP
Taiga Shield	TS
Hudson Plains	HP
Southern Arctic	SA
Northern Arctic	NA
Arctic Cordillera	AC

Marine ecozones	Codes
Pacific	PO
Atlantic	AO
Northwest Atlantic	AN
Arctic Archipelago	AA
Arctic Basin	AB

Source: Committee on the Status of Endangered Wildlife in Canada (1995). Ecozone information compiled by M.J. Kerr-Upal based upon the COSEWIC information in combination with range/distribution maps from COSEWIC status reports and various published wildlife authorities.

declines of Peregrine Falcons and Bald Eagles in the 1960s and 1970s signalled that the use of DDT and other synthetic chemical compounds was not ecologically sustainable. Currently, 13 species or subspecies of raptors that breed in Canada are listed by COSEWIC as endangered, threatened, or vulnerable — 7 of 21 diurnal raptors and 6 of 16 owls (Holroyd 1995). This is a higher proportion than in any other species group (Holroyd 1993). As top carnivores, raptors tend to have naturally low populations. This makes them particularly sensitive to human activities or natural events. Ten of the 13 raptor species listed by COSEWIC as of 1995 were in the vulnerable category (the rest were endangered or threatened), even though not all of these species are in decline.

Table 10.20

Number of endangered and threatened species, subspecies, and populations in each of Canada's provinces and territories and in each of the country's terrestrial and marine ecozones, 1995

	No. of species	
	Endangered	Threatened
Province/territory		
British Columbia	10	14
Alberta	6	8
Saskatchewan	6	7
Manitoba	6	6
Ontario	28	30
Quebec	10	17
New Brunswick	5	2
Prince Edward Island	2	1
Nova Scotia	11	7
Newfoundland	6	2
Yukon	2	1
Northwest Territories	9	4
Terrestrial ecozones		
Pacific Maritime	4	5
Montane Cordillera	4	7
Boreal Cordillera	0	0
Taiga Cordillera	1	0
Prairies	8	5
Boreal Plains	3	3
Boreal Shield	10	15
Mixedwood Plains	27	32
Atlantic Maritime	11	8
Taiga Plains	2	2
Taiga Shield	3	3
Hudson Plains	0	1
Southern Arctic	3	1
Northern Arctic	4	1
Arctic Cordillera	3	0
Marine ecozones		
Pacific	2	2
Atlantic	3	1
Northwest Atlantic	3	1
Arctic Archipelago	1	1
Arctic Basin	0	0

Note: If totalled, the number of species, subspecies, and populations for the above columns may exceed the total number in Canada for each risk category because some species are found in more than one province/territory or terrestrial/marine ecozone.

Source: Compiled by M.J. Kerr-Upal from the Committee on the Status of Endangered Wildlife in Canada (1995).

For many Canadian raptors, relatively little is known about their population status and trends. However, based on data from the Breeding Bird Survey, Christmas Bird Counts, and focused research programs, Kirk et al. (1995) were able to present "best guess estimates." They drew the following conclusions regarding population trends in recent years:

- Of the 21 diurnal raptors, 9 have apparently increased, whereas a further 9 appear stable over the long term. Possible evidence for declines over all or part of the Canadian range was found only for the Sharp-shinned Hawk, Swainson's Hawk, and Golden Eagle.
- Of the 16 owl species, 2 have increased over the long term, 3 have decreased (the Short-eared Owl, Spotted Owl, and Burrowing Owl, which COSEWIC elevated from threatened to endangered status in 1995), and 11 may be stable. However, there are too few data to adequately assess the status of many of the species presumed to be stable.

The 20th century has seen the number of wetlands in western Canada reduced by agriculture, urbanization, and, especially in the Prairies, series of dry years. Wetland margins have also been modified by agricultural practices, the effects of which accelerated during the drought of the 1980s. The associated lower productive capacity of wetlands, in conjunction with high harvest rates, has resulted in long-term decreases in the number of breeding ducks in western Canada and in the number of ponds that offer suitable breeding habitat (see Fig. 4.6 in Chapter 4). Figure 10.26 shows that, on average, Mallard populations in western Canada have declined by 18.9% from the average of the 1970s (the recovery goal of the NAWMP), whereas those of Northern Pintail have declined 73.6%.

Long-term data exist for the overall North American duck population. Surveys of migratory waterfowl in breeding areas in Canada, Alaska, and the north-central United States show a dramatic improvement in

duck populations for those areas in the 1990s, following a period of record low numbers in the 1980s. In 1995, the estimated breeding population of all ducks (excluding scoters, eiders, mergansers, Oldsquaws, and Wood Ducks) in the survey area was 35.9 million, an increase of 10% from the 1994 figure (Environment Canada and U.S. Fish and Wildlife Service 1995). The estimate was the highest since 1980. The increase likely was the result of good production in 1994 and good to excellent habitat conditions throughout most of the survey area in spring 1995 (Environment Canada and U.S. Fish and Wildlife Service 1995).

Two management programs have been in place during this period of increasing duck populations: the NAWMP's Prairie Habitat Joint Venture and a policy of restrictive regulations in Canada and the United States, resulting in reduced duck harvests. Despite feeling optimistic about the survey results, researchers remain cautious, as populations of several species are still below the target objectives of the NAWMP.

The surveys also indicate that populations of most goose species in North America have increased over the past few decades. This increase may be due to a combination of factors, including a warmer climate in the Arctic nesting areas and changes in agricultural practices in the areas of spring migration and on the wintering grounds. Adults returning to the nesting areas are in better condition than they used to be.

Wildlife conservation and protection

The cooperative challenge

With the growth of concern over wildlife issues, increasing numbers of government agencies, nongovernmental organizations, other special interest groups, and individuals are working together to preserve wildlife and sustain Canada's ecosystems. The involvement of such a broad range of groups has led to the strengthening of partnerships, which are needed to ensure that resources are used wisely and that efforts are directed to the best possible use. The following section explores a few of the approaches that are employed for wildlife conservation in Canada.

Policies, strategies, and legislation

The wide range of policies, strategies, and legislation includes A Wildlife Policy for Canada, the Canada Forest Accord, and the Federal Policy on Wetland Conservation, as well as numerous provincial and territorial conservation and sustainable development strategies, wildlife and wetland policies, forest management plans, and protected area strategies. One of these in particular — the Canadian Biodiversity Strategy — will build upon and knit together all of these efforts.

The Canadian Biodiversity Strategy represents Canada's first step in implementing the United Nations Framework Convention on Biological Diversity. The convention itself arose out of the 1992 Earth Summit (see above discussion in the "Land" section). The convention reflects a global consensus on the need to halt the loss of biodiversity around the world (see Chapter 14).

The Canadian Biodiversity Strategy sets the stage for all jurisdictions in Canada to identify the actions that need to be taken, both individually and in partnership with others. It establishes a comprehensive planning framework within which Canadians can participate in the effort to conserve biodiversity.

There are management policies, programs, and laws to protect wildlife in each province and territory of Canada. Despite

Table 10.21
Breeding Bird Survey trends, 1966–1994

	% annual change in population					
	Habitat type			Migration pattern		
Terrestrial ecozone[a]	Forest	Scrubland	Grassland	Long-distance migrant	Short-distance migrant	Resident (nonmigrant)
Pacific Maritime	–0.9	–1.1	–2.8	–1.4[n]	–1.3	+0.6
Montane Cordillera	+0.3	+1.7[s]	+0.4	+0.3	+0.2	+0.1
Boreal Plains	+1.6	–0.3	–0.6	+0.3	–0.2	–0.2
Prairies	+1.9[s]	+0.5[n]	–0.6	0.0	–0.1	–0.7
Boreal Shield	+0.2	–0.7[n]	–1.6[s]	0.0	–0.7[s]	+2.9[s]
Mixedwood Plains	+1.4[n]	+0.3	–2.3[s]	–1.5	–0.4	+0.2
Atlantic Maritime	0.0	–1.3[s]	–2.5[s]	–0.5[n]	–0.7[s]	–0.3
Canada[b]	+0.2	–0.5[s]	–1.2[s]	–0.2	–0.4[s]	0.0

[s] = trends statistically significant; [n] = trends nearly statistically significant; for others, trends not statistically significant.

[a] Insufficient data were available to calculate trends for the three Taiga ecozones and the Boreal Cordillera and Hudson Plains ecozones, and no data were available for the three Arctic ecozones.

[b] Average for the terrestrial ecozones where sufficient data existed.

Source: C. Downes, Canadian Wildlife Service, Environment Canada, personal communication.

this, some 243 species, subspecies, or populations are classified as endangered, threatened, or vulnerable (see above discussion). Recently, provincial, territorial, and federal governments have been working to develop a harmonized national approach to conservation of species at risk in Canada (Committee of Federal, Provincial, and Territorial Government Wildlife Officials 1995). The ultimate goal of the proposed approach is to prevent any species from becoming extinct as a consequence of human activities. One underlying precept of such an approach is that all Canadians share responsibility for the conservation of wildlife at risk. A second is that an effective and complete national endangered species framework must be able to address all nondomesticated living organisms native to Canada.

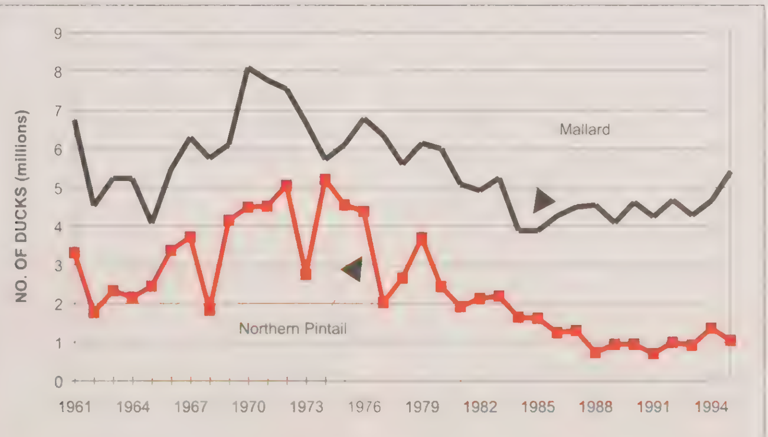
The Government of Canada is currently developing federal endangered species legislation. At the time of writing, consultations were being held with various federal government departments, the provinces and territories, nongovernmental agencies, Aboriginal groups, resource sector interests, and the public. A draft bill is planned for introduction in the House of Commons in summer 1996. Ontario, New Brunswick, Manitoba, and Quebec are the only provinces that currently have endangered species legislation.

In June 1994, Parliament passed amendments to the *Canada Wildlife Act* and to the *Migratory Birds Convention Act*. Penalties were significantly increased for violations to both acts. One of the more substantive changes to the *Canada Wildlife Act* was broadening the definition of wildlife from any nondomestic animal to all wild organisms. In December 1995, Canada and the United States signed amendments to the Migratory Birds Convention to improve the management of birds that migrate between the two countries and to provide fairness in the regulation of waterfowl harvests to Alaska's and Canada's Aboriginal peoples. Ratification of the amendments will lead to increased collection and exchange of information, expanding the scientific base for migratory bird management.

Chapter 14 provides a global perspective on the issue of biodiversity change. However, one international agreement is worth noting here because of its implications for wildlife in Canada. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) regulates trade in particular species of wild animals and plants, as well as their parts and derivatives (Environment Canada 1993d). To help fulfil Canada's obligations as a signatory to CITES, the *Wild Animal and Plant Protection and Regulation of International and Interprovincial Trade Act* is aimed at improving Canada's ability to diminish illegal trade in wildlife.

Figure 10.26

Trends in the sizes of breeding populations of Mallard and Northern Pintail in western Canada, 1961–1995



Source: K. Dickson, Canadian Wildlife Service, Environment Canada, personal communication; Strata 12–40, 50, 75–77.

Protected areas: ensuring habitat conservation

All plants, animals, and microorganisms need *habitat*. Habitat is a location or type of location with specific characteristics, such as a certain climate and the availability of water and other life requisites, which make it especially well suited to meet the life cycle needs of the particular organism. Animals that migrate, such as Caribou and many birds, need several habitats. They often breed in one type of ecosystem during the summer, pass the winter months in another, and migrate along traditional routes during spring and fall. To conserve abundant and diverse wildlife populations in Canada, it is essential to conserve both the *quality* and the *quantity* of suitable habitat.

Canada is increasingly using a two-pronged ecosystem approach to habitat conservation, which provides for:

- ecologically sound use of resources, as well as environmental protection of all Canadian ecosystems. This requires integrated management of all resource sectors, with sectors working together to mitigate environmental damage and enhance habitats; and
- national networks of representative protected areas.

This all-round approach to habitat conservation recognizes both the value of protected areas and the importance of maintaining ecosystem integrity in those protected areas and across the entire landscape. Canada's networks comprise a great range of types of protected areas and involve the cooperation of agencies at all orders of government, nongovernmental organizations, the private sector, and the

general public. Chapter 14 and the "Land" segment of this chapter provide national overviews of Canada's protected area networks, and Chapters 3–9 examine regional programs and specific examples of protected areas.

In Canada, all orders of government, nongovernmental organizations, the private sector, and individuals are involved in ecosystem protection. Traditionally, governments acquired areas through direct purchases, but now they are increasingly entering into partnerships with nongovernmental organizations, private landowners, and Aboriginal groups to secure and manage areas (Turner 1995). Nongovernmental organizations play a key role in protecting ecosystems because they typically concentrate their efforts in the most modified ecosystems of southern Canada, where ecosystem integrity is often the lowest. Here, through acquisition or partnership agreements with landowners, they obtain remnants of wilderness, often containing important specialized habitats or species at risk. For example, the Nature Conservancy of Canada secures areas through direct purchases and then coordinates its activities with other nongovernmental organizations, which directly manage the areas.

The NAWMP is perhaps the most ambitious wildlife habitat conservation program ever undertaken in Canada (Käärik 1994). Launched in 1986, the NAWMP is a billion-dollar combined initiative of Canada, the United States, and Mexico. It responds to public concern over the loss of North American wetlands and the consequent reduction in populations of waterfowl and other species that depend on wetland habitats. Its overriding goal is to protect and enhance high-quality wetland habitat in North America.

This innovative partnership program is implemented through regionally based joint ventures, which involve federal, provincial/territorial, and state government agencies, nongovernmental organizations (e.g., Wildlife Habitat Canada and Ducks Unlimited Canada), the private sector, and landowners cooperating together across the continent. Regional habitat management in Canada is through the Prairie Habitat, the Eastern Habitat, and the Pacific Coast joint ventures, the last of which is composed of both Canadian and U.S. representatives. Two cooperative joint ventures have also been created to fill research and monitoring gaps specifically for American Black Ducks (the Black Duck Joint Venture) and Arctic geese (the Arctic Goose Joint Venture).

Over the years, what was initially conceived of as a waterfowl plan has expanded to include multispecies and biodiversity objectives (Käärik 1994). In much of the area covered by the NAWMP, a landscape approach is applied to attaining the plan's objectives. For example, in the vast Prairies, where policies affect the landscape on a large scale, the NAWMP focuses on subregional activities that harmonize wildlife habitat objectives with those of soil and water conservation. The NAWMP was renewed in 1994 for an additional five years. As of late 1994, Canada had secured 3 355 km^2 of wildlife habitat through the plan's joint ventures (Government of Canada 1995b).

In recent years, industry has been an active player in protecting key areas. Resource companies have voluntarily relinquished oil, gas, mineral, or logging rights or whole lands in the interest of protection. For example, in 1992, Shell Oil donated a large holding in British Columbia to the Nature Conservancy of Canada. Forest companies have a long history of donating land for its ecological values. Cathedral Grove, perhaps the best-known stand of old-growth forest in the country, was donated by MacMillan Bloedel in the 1940s. In New Brunswick, Bowater-Mersey Forest Products Ltd. periodically donates areas such as wetlands that have important ecological benefits. These areas are either returned to the government or managed for conservation purposes by nongovernmental organizations.

Aboriginal people are increasingly becoming active participants in the establishment of protected areas. Land claim settlements often direct portions of lands to be set aside as protected space, typically involving comanagement arrangements with government. Several recent national park reserves in northern Canada remain subject to future land claim settlements.

Private individuals can also play a significant role in securing protected areas. Landowners, for example, can participate in various stewardship programs, or they can donate areas to conservation groups or governments.

Recovery and rehabilitation programs
In 1988, federal and provincial wildlife agencies and nongovernmental agencies established a national committee called Recovery of Nationally Endangered Wildlife (RENEW) to rehabilitate species in danger. Under RENEW, teams of experts develop recovery plans for individual terrestrial animal species that have been designated by COSEWIC as extirpated, endangered, or threatened. Since 1988, nearly $13 million has been spent by almost 200 cooperating organizations on recovery efforts for endangered species of wildlife in Canada (RENEW 1995). As of April 1996, recovery teams were in place for 34 species, subspecies, and populations (S. Nadeau, RENEW Secretariat, Canadian Wildlife Service, Environment Canada, personal communication).

The Endangered Species Recovery Fund (ESRF), a joint program of the World Wildlife Fund and Environment Canada, is aimed at improving the status or arresting the degradation of endangered wildlife and habitat. The ESRF has funded 18 organizations working on RENEW species (RENEW 1995).

Controlling nonnative "pest" species using biocontrols
A great many introduced plants become strong competitors not only with native plants but also with agricultural crops. Attempts to eradicate such invasive plants with herbicides result in only temporary controls. As well, herbicides have a number of other effects, including the killing of nontarget plant species, soil microorganisms, birds, and other wild animals and the contamination of groundwater and both fresh and marine surface waters.

Introduced plants generally have natural predators — particularly insects — in the regions where they originated, which help to keep their populations under control. Research in recent decades has demonstrated that reuniting introduced pest plants with the insect predators from their homelands can provide long-term, inexpensive, and environmentally safe control. The introduction of these insects, though, is not undertaken without extensive evaluation of the potential consequences for native Canadian biota and agricultural crops. It may take 20 years and cost \$4–7 million to be certain that these insects can be reunited with the introduced plants without endangering native plants or crops (Harris 1994).

The Agricultural Weed Biocontrol Program, started in 1952, is based at Agriculture and Agri-Food Canada's research station at Lethbridge, Alberta. To date, 60 species of insects have been released against 25 nonnative plant species (Harris 1994). About one-third of these insects have become well established and provide some measure of control of the target nonnative species, another third have become established but survive only at low densities, and the remaining third failed to survive owing to an inability to adapt to the Canadian climate or for other reasons.

The majority of biocontrols have been initiated to help control weed species on agricultural lands. However, three species of insects were recently introduced to help control the spread of Purple Loosestrife, a species that is considered a major threat to North American wetlands and other types of ecosystems (see Box 10.7).

Biocontrols can also be used as nonchemical alternatives to animal-targeted pesticides. For example, every year humans wage war against mosquitoes in various regions of Canada. In parts of the Prairie provinces, the battles are typically fought by spraying sloughs and other breeding grounds with chemical insecticides — which can kill more than just the target mosquitoes (Roy-Sole 1994). Red Deer, Alberta, however, has developed a control that uses bacteria as a more environmentally friendly way to reduce the insect problem. The city applies a larvae-killing bacterium — *Bacillus thuringiensis israelensis* (BTI) — to the vegetation surrounding mosquito breeding grounds. Once ingested by mosquito larvae, BTI breaks down and releases spores containing a deadly toxin. The result has been an average 85% reduction of the area's mosquito population. BTI does not seem to harm other insects, other invertebrates, or vertebrates, nor does it appear to have any adverse effects on the water bodies themselves. BTI is completely biodegradable within 48 hours and is applied selectively to kill only three species of mosquitoes that tend to bite humans (G. Moir, Red Deer Parks Department, personal communication, cited in Roy-Sole 1994).

Minimizing toxic chemical contaminants in the environment

Chapter 13 provides examples of efforts to deal with toxic chemical contaminants that pose threats to wildlife. Of particular note at the national level is the development of the Priority Substances List under CEPA. Additional information on specific programs is provided in some of the ecozone groupings chapters (e.g., Chapter 3, Fraser River Action Plan; Chapter 6, Remedial Action Plans for the

Box 10.7
Biocontrols in action: nonnative beetles and weevils battling Purple Loosestrife

The rapid spread of Purple Loosestrife throughout much of southern Canada demonstrates the sort of habitat change that can occur when nonnative plant species are introduced. Purple Loosestrife principally invades wetlands, where its thick tangles of roots and stems crowd out native plants such as cattails, sedges, and bulrushes (Bennett 1994). The species ultimately creates a dense rose-purple carpet that is unsuitable as habitat for most species of native animals and plants. It is now recognized as a pervasive threat to North American wetlands. Hand-pulling, flooding, mowing, burning, and various other methods of defence have proved ineffective as long-term controls for this invader.

Native to Eurasia, Purple Loosestrife probably arrived in North America in the early 1800s (White et al. 1993). It has since spread across much of the continent. It appears to have entered Canada between 1880 and 1900 and can now be found from British Columbia to Newfoundland, with greatest concentrations occurring throughout southern Ontario and western Quebec (White et al. 1993). The plant is hardy and adaptable, and its unrelenting spread has been greatly aided by the absence of native predators (Ducks Unlimited Canada 1994).

To try to control the spread of Purple Loosestrife, researchers began to look for help outside North America. In 1992, two types of nonnative leaf-eating beetles were introduced into stands of Purple Loosestrife in Ontario; in 1993, a nonnative root-boring weevil was introduced to the battleground (Bennett 1994). Scientists in British Columbia, Alberta, Manitoba, and Prince Edward Island are working on similar projects.

The key question has been whether the three introduced insect species might move beyond Purple Loosestrife to attack native wild plants or domestic horticultural or agricultural varieties. Many laboratory and field tests have been conducted since the mid-1980s in Europe and North America, and researchers and government regulatory agencies feel confident that the insects feed only on Purple Loosestrife (J. Laing, University of Guelph, personal communication, cited in Bennett 1994). Two additional species of insects have recently been added to the roster of approved biocontrols, and others currently being examined will be subject to the same assessments (G. Lee, Canadian Wildlife Service, Environment Canada, personal communication).

Great Lakes basin; and Chapter 9, Arctic Environmental Strategy).

Generally speaking, existing control measures have resulted in substantial declines in environmental residue levels of DDT/DDE, PCBs, mercury, and lead. However, these declines appear to have reached a plateau in a number of areas. Although levels represent a marked improvement from the record highs experienced in the 1960s and 1970s, they are still far above historic conditions (see Chapter 13). This plateauing effect is caused by ongoing releases from human activities and waste management sites (often from areas of the world where controls are not in place), combined with recirculation of contaminants previously emitted. Concentrations remain at levels that are potentially harmful to wildlife.

Wildlife in Canada and sustainability: a brief assessment

Canada encompasses a great wealth of wild, living organisms. However, wildlife continues to be under pressure throughout the country from a wide array of human activities as well as natural phenomena. Agriculture, forestry, fishing, and urban and industrial development, among others, continue both to exert direct pressures on wildlife and to effect changes in the quality and quantity of their habitat over large areas. The results are seen in the increasing numbers of species recognized to be at risk of eventual extinction. They are reflected in the presence of toxic contaminants in tissues of living organisms: DDT/DDE, PCBs, and other persistent organochlorine chemicals; mercury, lead, and other metals. Populations of some species are declining, such as certain songbirds in southern Canada and some species of fish in Canada's freshwater and marine ecosystems. Nonnative species continue to invade Canadian ecosystems, and many that invaded years ago, such as the Purple Loosestrife and Zebra Mussel, continue to expand into new habitats, providing strong competition for or even overpowering native species. Climate change continues to pose threats to native wildlife, largely through potential significant changes to existing habitats.

Despite all this, there are many encouraging signs. Progress is being made in the identification of endangered, threatened, and vulnerable species and in the formulation of plans to protect them and restore their habitats. Populations of all North American ducks and most species of geese have been on the rise in the 1990s. Levels of most toxic contaminants in the tissues of living organisms have decreased significantly since the 1970s and 1980s. As well, regulations are in place or voluntary industry initiatives have been taken to control emissions of the majority of the most significant toxic substances, such as the persistent organochlorines DDT/DDE and PCBs. In the case of toxic metal contaminants, initiatives include the substitution of less toxic material for lead in shot for hunting and sinkers for fishing. New federal legislation has been passed to protect wildlife (e.g., the *Wild Animal and Plant Protection and Regulation of International and Interprovincial Trade Act*), and existing legislation has recently been updated and significantly strengthened (the *Migratory Birds Convention Act* and the *Canada Wildlife Act*). Further, Canada continues to protect ecosystems, adding to its networks of national, provincial, and territorial parks, national wildlife areas, migratory bird sanctuaries, areas protected through landowner stewardship programs, and so on.

Our awareness and understanding of the current status of Canada's wildlife — and of likely trends for the future — depend largely on the systematic collection of accurate data for scientific research and analysis. Although it is possible to roughly sketch conditions and trends affecting Canada's wildlife today, too little is known about most species and communities to be confident that their future sustainability is assured. Much more needs to be known before Canadians will be able to anticipate and prevent irreversible declines in species populations and the permanent loss of biodiversity.

Conclusion

Based on the reviews in this chapter, a reader might be inclined to conclude that no problem is ever totally resolved and that environmental problems constantly increase in complexity. Environmental issues have come to influence virtually every aspect of daily life, from how breakfast cereal packages are constructed and eventually disposed of to how trade and environment policies are balanced and made mutually supportive. There seems little prospect that environmental concerns will subside in the foreseeable future, if only because more and more environmental problems seem to have important, and sometimes unexpected, consequences for individual health and well-being.

If few major environmental problems have been "solved," substantial progress has been made on many of them in recent years. Progress of a kind has been achieved if a problem has been recognized, research on it is under way, and relevant data are being collected. However, on several fronts, the progress goes considerably further than this. In the case of stratospheric ozone depletion, it seems that the basic elements for a solution are in place, even if full restoration will require half of the 21st century to complete. The Montreal Protocol demonstrated that the world community is able to act, and act quickly, on behalf of the global environment. Promptness in this case was no doubt considerably assisted by the fact that alternatives to CFCs and halons were available and that the release of these contaminants could, over the long run, be controlled by a relatively small number of nations and manufacturers. Similarly, North America is on the way to reducing acidic deposition, enabling lakes and other aquatic ecosystems to be rehabilitated. Unless climate change reverses the trend, prospects are good that the frequency and severity of photochemical smogs in major cities will continue to decline as control and reduction measures are extended.

For every piece of good news, however, it seems that there is another area where progress has been much more difficult.

The world community's readiness to act in regard to stratospheric ozone protection has not been matched by any similar enthusiasm to take strong and collective action to prevent global warming. Yet climate models estimate that the direct effects of global warming would include changes in the frequency and amount of precipitation, a tendency towards increased drying of continental interiors, a rise of sea level, changes in ocean currents, a thawing of permafrost, and the melting of snow and sea ice. Canada is working, via its National Action Program on Climate Change, to achieve its commitment to stabilize net greenhouse gas emissions at their 1990 levels by the year 2000. Canada's progress will be reviewed regularly. The federal government will continue to work with provincial, territorial, and municipal governments and nongovernmental stakeholders to ensure that Canada is on track to meet its climate change commitment. On another front, despite nearly 20 years of action by Canada and the United States, the International Joint Commission reports that neither zero discharge nor virtual elimination of *any* persistent toxic substance in the Great Lakes has yet been achieved. "Indeed, we have not even come close to elimination" (International Joint Commission 1994).

Although the land is such a familiar environmental element, it continues to pose significant challenges. As the 1991 State of the Environment Report noted (Government of Canada 1991c): "At every level — national, provincial, regional, and local — our knowledge of the land base itself is inadequate.... Nationally, Canada has not determined how much land will be needed for different purposes in the future, nor is there agreement on how to establish the true value of various land uses, to compare with those established by the market."

Some attention has been paid to this problem in the last five years, most notably in the Lower Mainland of British Columbia, where there is stiff competition among alternative uses for the relatively small amount of lowland. However, the situation has not changed fundamentally, and environmental objectives frequently clash with the rights associated with individual land ownership. The long-standing tradeoff between individual and collective "rights" has now been extended into the environmental field, as jurisdictions come up with approaches such as their own Environmental Bill of Rights. The notion that every right also implies a responsibility has received less attention, yet an Environmental Bill of Responsibilities, binding upon both individuals and institutions, seems a more realistic way to promote environmental protection and sustainability.

What emerges clearly from the review of environmental issues in this chapter is that the human ability to influence and shape the state of the environment is huge and increasing. It is to a review of some of the most important of these human activities, therefore, that we must turn in Chapter 11.

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Chapter 11 Human Activities

Highlights

Agriculture

Some agricultural lands remain at high risk of degradation from wind and water erosion, salinization, soil compaction, and organic matter loss. In addition, the protection of water quality has emerged as one of the key environmental challenges facing agriculture in the 1990s. Nitrate is found in virtually all groundwaters in the agricultural regions of the country; levels are usually below recommended safe limits, but areas of intensive agriculture and areas under heavy manure application or irrigation are prone to levels above safe limits. Other agricultural contaminants, such as pesticides and bacteria, have also been detected in certain areas.

■

Considerable progress has been made in ensuring long-term sustainability of agroecosystems through the increased use of sustainable land management practices. For example, in 1991, conservation tillage (including no-till) was used on about one-third of Canada's cultivated land, compared with minimal use 10 years earlier; there was a 27% reduction in summerfallow between 1971 and 1991; and changes in cropping and tilling practices resulted in a 7% decrease in the risk of wind erosion in the Prairie provinces between 1981 and 1991 and a decrease of 11% in the risk of water erosion in Canada during the same period. Initiatives aimed at minimizing water pollution include improving manure storage and management and more selective application of pesticides and fertilizers.

■

Forestry

Nationally, area harvested is minimal compared with area affected by natural disturbances. Regionally, however, harvesting may be a major agent of disturbance. Clear-cutting, while controversial, remains, by far, the preferred harvest method of industry. The harvest of old growth continues to be an issue of major regional significance.

■

Positive trends include greater efforts to regenerate trees removed by harvesting (between 1975 and 1993, the area harvested increased by 42%, whereas the area planted or seeded increased by 228%); reduced pollution from pulp and paper mills (almost all are meeting current effluent standards); increased use of recycled material for pulp and paper production (the amount has tripled since 1980); and large declines in the use of chemical pesticides — a trend that is expected to continue with increasing use of biological insecticides.

■

Fisheries

Many groundfish stocks in the northwest Atlantic and some salmon stocks on the Pacific coast have been overharvested. Some fisheries have been closed on the Atlantic coast. Overharvesting, inappropriate fishing practices, changes in environmental conditions, and changes in predator and prey abundance all contributed to the severe decline in stocks. The ability to harvest some marine resources (excessive amounts of labour and capital in the industry) exceeds sustainable levels. Assessment, monitoring, and conservation of fishery resources need strengthening.

■

Many initiatives are contributing to more sustainable fisheries for the future. For example, new management approaches include taking a "fish first" view to managing the fishery; setting cautious harvest levels; a larger role for the harvesting industry; increased industry–government partnerships to improve information on stock status and reduce harvesting to sustainable levels; a transition to a truly multispecies approach; the introduction of individual quotas; and reduction of fishing capacity and workforce.

■

Minerals, Metals, and Mining

There are a number of environmental concerns related to the mining, smelting, and refining of minerals and metals. Acidic drainage is the largest environmental problem facing the global metal mining industry. In Canada, there are an estimated 12 500 ha of acid-producing tailings and 739 million tonnes of acid-generating waste rock. Smelting and some refining take place in furnaces at high temperatures. Emissions from these furnaces include sulphur dioxide, particulate matter, and heavy metals. The largest emission source of sulphur dioxide in Canada is the smelting of metal concentrates,

which contributed 50% of total eastern Canadian sulphur dioxide emissions in 1994. Post-operational waste management is a major long-term issue because of high costs, the number of sites, and the limited number of technical options.

■

Canada has a significant recycling industry. During 1994, Canadian trade in recyclable metals exceeded 4 million tonnes, valued at over $2 billion. By reducing demand for "new" metals, recycling has significant environmental benefits, including reduced discharges to water and air, reduced habitat disruption, and overall energy savings. There have been substantial reductions in quantities of sulphur dioxide released from eastern Canadian smelters and refineries owing to a combination of equipment installation and changes in metallurgical processes since the 1980s. In recent years, various multistakeholder cooperative programs have been launched to further reduce the environmental impacts of mining. The Whitehorse Mining Initiative, the Assessment of the Aquatic Effects of Mining in Canada process, the Aquatic Effects Technology Evaluation program, the Mine Environment Neutral Drainage program, and the Accelerated Reduction/Elimination of Toxics program indicate that it is in the best interests of all concerned to work together to develop and implement sound environmental policies and practices to ensure sustainable development.

■

Energy Use

Energy production and use are leading sources of atmospheric pollutants that contribute to climate change, acidic deposition, and urban smog. About 90% of Canada's human-produced emissions of carbon dioxide arise from energy usage, with fossil fuel use accounting for 98% of this total in 1992. Without further action, carbon dioxide emissions are expected to increase by 10–20% between 1990 and the year 2000. Energy-related sources also account for about 55% of sulphur dioxide emissions, 90% of nitrogen oxide emissions, 55% of volatile organic compound emissions, and 35% of methane emissions. In addition, about 70% of the total carbon monoxide emissions in Canada are energy related.

■

Progress is being made in controlling pollution from energy systems. Under the Canadian Acid Rain Control Program, national targets for aggregate sulphur dioxide emissions were met ahead of schedule. In addition, a comprehensive management plan to control nitrogen oxides and volatile organic compounds was agreed to by the Canadian Council of Ministers of the Environment in 1990. Under the Framework Convention on Climate Change, Canada has committed to aim at stabilizing greenhouse gas emissions at 1990 levels by the year 2000. It is unclear at the moment whether Canada will be able to meet this objective. However, governments, industry, and other stakeholders are now working together to develop programs and measures that will facilitate meeting this goal.

■

Transportation

Innovation and regulation have resulted in impressive gains in fuel efficiency and emission control on a per vehicle–kilometre basis in Canada during the past 20 years. The average Canadian passenger vehicle (in-use fleet) improved 39% in energy use per kilometre travelled between 1974 and 1994. Similarly, the average new car in 1990 produced only 24% of the nitrogen oxides, 4% of the volatile organic compounds, and 4% of the carbon monoxide of a new car in the early 1970s. However, gains in energy efficiency and emission reductions per vehicle based on improved technology have slowed in recent years and are being offset by the fact that Canadians now own more vehicles per capita and, on average, drive them further annually.

■

Barring a fundamental breakthrough, technological innovation alone in transportation systems is insufficient to bring about lasting change towards more environmentally sustainable transportation in Canada. Significant changes by millions of Canadian households in the way they use the automobile and other transportation modes will be required. Many Canadian communities are pursuing a variety of initiatives to improve the sustainability of transportation, ranging from urban design and demand management to transit efficiency and education/outreach. However, many of these efforts are currently at the planning or testing stage, not the action or achieving stage. Transportation involves every member of society and all levels of government; hence, a high degree of cooperation is required to effect long-term, sustainable, and equitable results.

■

Manufacturing

Manufacturing is a significant contributor to atmospheric emissions. In 1990, 23% of total sulphur dioxide emissions, 21% of particulate emissions, 4% of total nitrogen oxide emissions, and 4% of volatile organic compound emissions were from manufacturing.

■

Depletion of the stratospheric ozone layer has been linked to the action of a number of manufactured chlorine and bromine compounds. Under the Montreal Protocol of 1987 and subsequent amendments, action by government, the scientific community, industry, and individuals has led to a decrease in new Canadian supplies of ozone-depleting substances, from 27.8 kt in 1987 to 5.7 kt in 1994.

■

Outdoor Recreation and Tourism

In 1992, Canadians took 97 million overnight trips, 55% of which were to small city, town, rural, and wilderness destinations. Activity on this scale has substantial consequences for the environment, particularly in terms of transportation-related impacts, resource consumption, and disruption of wildlife habitat and natural ecosystems. Recreation and tourism have provided Canadians with considerable economic returns, which are well documented; their social and their environmental significance are not.

■

Given the scarcity of data and analysis on the environmental effects of recreation and tourism in Canada, it is difficult to draw firm conclusions about their overall implications with respect to environmental sustainability. Nevertheless, visitor/tourism facilities are a major source of ecological impact on specific areas such as parks. To deal with some of these impacts, governments and industry are developing management tools and strategies, including awareness program development, codes of ethics and conduct, and environmental impact and other studies.

■

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Introduction

The clear message of Chapter 10 is that all the main components of the natural environment are under pressure from human activities. Chapter 11 examines these activities in terms of eight economic sectors, assessing their impact on different aspects of the environment. It looks at how successful Canada has been in recent years in reducing these pressures, and it discusses the progress of these economic sectors in moving towards sustainability.

The sectors chosen for review do not represent the totality of the Canadian economy, nor are major impacts on the environment limited to these activities. Taken together, however, they exemplify the scale and character of economy–environment linkages and the opportunities for and threats to sustainability. Four of these sectors — agriculture, forestry, mining, and manufacturing — account for a large proportion of Canada's economic growth and prosperity, as measured by indicators such as gross domestic product (GDP) and value in external trade. Others, such as transportation and energy use, reflect lifestyle choices as well as economic activity. The component on outdoor recreation and tourism demonstrates that such lifestyle choices may themselves become both a principal economic sector and a major environmental stress.

There is clear evidence, from opinion surveys and other sources, that Canadians care deeply about environmental values and strongly desire a sustainable future. That, however, does not equate to taking, and maintaining over the long term, the necessary actions on an individual, local, and national scale. How adequately are words translated into deeds?

Not surprisingly, Chapter 11 provides mixed answers. The response differs from one economic sector to another, within individual sectors, and, no doubt, within individual firms. It varies from place to place and, given changing priorities, from time to time. The chapter records both environmental successes and failures.

It is clear, however, that the era when environmental issues had to struggle for a place on the national agenda is long gone. The reports from different economic sectors clearly show that the environment has become a factor of production, added to the labour, land, and capital of traditional economics. For example, as stated in the "Minerals, metals, and mining" component, "The increasing attention being paid to reducing the environmental stress imposed by mining is, almost without exception, resulting in significant economic benefits. Reductions have been made in the use of water, processing chemicals, and energy, leading to significant cost savings. Without exception, these reductions are linked to improvements in process efficiencies, which themselves generate savings. In addition, new export opportunities have emerged for equipment, processing, engineering, and management systems." Similarly, in the "Agriculture" component, it is noted that "Initiatives related to sustainability of agroecosystems have historically focused on stewardship of private on-farm resources, primarily land and soil. More recently, efforts have also expanded to address off-farm concerns from agriculture, such as water quality and biodiversity."

Often, the changes in attitude involve well-established beliefs or assumptions and may sometimes alter the basic raison d'être of an entire industry or economic sector. For instance, forest policies in Canada are shifting from management for sustained timber yield to sustainable forest ecosystem management. Such a shift is not accomplished easily or quickly. Apart from any other considerations, it demands the introduction of new skills and expertise at all levels, from forest workers to senior management, which may take a generation to complete.

The discussion of Canada's energy situation in Chapter 11 provides a broader context on changing attitudes. In the early 1970s, during an unexpected world crisis in petroleum supply, there seemed good reason to believe that depletion of basic natural resources would impose rigid "limits to growth." Nowadays, that component argues, resource depletion seems less likely, and the real limits to growth may be environmental, not resource related. "Instead, the debate has shifted from whether society is likely to run out of energy to whether the environmental impacts of energy production and use can be kept within the carrying capacity of the ecosystem."

Some environmental philosophers and activists have advanced similar arguments for a long time. What has changed in the 1990s is that such concerns have become an accepted part of the mainstream of public debate. The discussion has shifted to specifics: How can economic and environmental objectives be reconciled in a particular industry? How much time is there for the changes to be accomplished? Will the necessary action be voluntary, or must it be compelled by legislation, regulation, and enforcement?

What emerges, rather surprisingly, from the following sections is that the shift towards specifics seems to have gone furthest in those economic sectors traditionally regarded as the principal sources of environmental pollution. This movement is less apparent in others that have appeared more benign or in which the prosperity of the sector depends directly on environmental quality and resource conservation. Thus, the chapter components dealing with energy production, mining and mineral processing, and manufacturing provide detailed accounts of pollution reduction programs and similar actions, as well as data on what these have achieved and what targets have been established for the next 5–10 years. There is, of course, plenty of scope for disagreement about the significance of such actions. Have the most important problems been adequately tackled, or is the sense of progress rather illusory because the easiest and cheapest solutions have been applied first?

Such information is less abundant in sectors such as fisheries, agriculture, and recreation. In the marine fisheries, in particular, it is clear that knowledge of the relationships among environmental factors, resource conservation, and fishing practices is inadequate. There is, for example, no simple explanation for the collapse of the Northern Cod fishery in the northwest Atlantic; "what was generally

considered to be a stringent conservation regime" did not prevent this collapse, possibly in part because it assumed a degree of stability in the marine environment that has not been characteristic of recent years. In the agricultural sector, it is not difficult to determine what should be done or even, in most cases, to show that such actions are likely to be neutral or even beneficial in terms of economic cost. The problem is to ensure that the action is taken throughout the extensive agricultural areas where it is needed.

Whereas sustainability in agriculture needs more effort and the conditions for sustainable fisheries need to be redefined, the "Outdoor recreation and tourism" component of this chapter suggests that Canadians have not yet faced up to the potential conflict between recreation and environmental sustainability. The absence of comprehensive and detailed information on the environmental costs and effects of outdoor recreation and tourism across Canada suggests that assessing the impacts of recreation and tourism on the Canadian environment is still in its infancy. The difficulties of balancing environmental needs and economic objectives, as well as reconciling past legacies with current sustainability objectives, are illustrated in Banff National Park.

Sustainability in transportation is a study in contrasts. Progress has been made in producing more fuel-efficient vehicles, using cleaner fuels, and improving the emission performance of individual vehicles. On the other hand, there are more vehicles per capita, there are more two-vehicle households, and the average annual distance driven per vehicle in Canada is rising. These factors offset many of the environmental gains made through improved technology. Although the situation is beginning to change, urban growth in Canada continues to be characterized by low-density development on the fringe, reinforcing the trend towards increased vehicle use and increasing the difficulty of achieving a more environmentally sustainable transportation system.

If, for most Canadian economic activities, there is a general acceptance that future development must be environmentally sustainable, then the way is open for a more productive debate on what this involves in specific activities and for individual regions, ecozones, and sites. That debate is taking place in many forums, notably the round tables on environment and economy that have been established at national, provincial/territorial, and other levels across Canada. It is also evident in individual sectors — for example, in the Whitehorse Mining Initiative.

To participate effectively in such debates may require an evolution in attitude and understanding by all segments of society. All groups must be prepared to work together to balance competing demands. Many firms, trade associations, and managers of the activities considered in this chapter have made considerable progress in this area. Getting environmental concerns onto the public agenda has been achieved mainly by the active work of environmental groups, aided by clear evidence of cumulative effects of pollution and memorable environmental crises. Moving towards a sustainable future, to a situation where sustainable development issues are incorporated into all decision-making processes, is likely to be much more challenging. It will require, to begin with, a willingness on the part of all parties to recognize when progress is being made.

This chapter is one of the many information and data sources designed to make the debate on sustainable development paths as productive as possible. It is necessarily detailed, because much is happening, but it is inevitably also superficial: there is space only to describe the effect of environmental action in major economic sectors in broad terms and through a few specific examples. Chapter 11 invites the reader to consider major human activities in Canada in terms of the following crucial questions:

- Does each economic sector adequately recognize the environmental and social aspects of sustainability, or is it still driven mainly by economic priorities?
- To what extent does long-term environmental, economic, and social sustainability shape the broad policies of each sector? What priority is given to long-term sustainability as opposed to short-term profitability?
- Do the environmental actions that have been taken reflect an understanding of ecosystem linkages and relationships, or are they primarily responses to specific crises?
- Is the action that is being taken to promote sustainability on a scale appropriate to the need, or is it still at the stage of good intentions or limited experiments?
- Is the pace of change fast enough to secure a sustainable future, or is success defined only as progress in the right direction?

These are very different questions from those that were being asked a decade or so ago, and there are no easy or general answers. They are, nevertheless, among the questions that need to be answered in the mid-1990s if Canada is to make progress towards a sustainable future.

Agriculture

Introduction

Agriculture and the agri-food sector are important contributors to the Canadian economy. In 1993, primary agriculture contributed \$23.8 billion (2.1%) to Canada's GDP; food processing contributed a further \$39.9 billion (Canadian Federation of Agriculture 1995). In addition to the 391 000 persons operating farms, Canada's agri-food sector employs more than 1 million persons in food processing, packaging, retailing, and transportation (Statistics Canada 1994a). Canada is a net exporter of farm products. In 1994, Canadian agricultural exports were valued at \$15.2 billion (6.8% of total exports), whereas agricultural imports amounted to \$11.9 billion (5.9% of total imports) (Canadian Federation of Agriculture 1995).

Canada's agricultural land base is far more limited than most Canadians appreciate. Only 11% of Canada's land is capable of supporting any form of agriculture; less than 5% is capable of producing crops. Canada has no vast agricultural reserves

remaining. Virtually all the land that is amenable to agricultural production that is neither built upon nor paved over is in agricultural use today (Fig. 11.1). The challenge of farming sustainably is to maintain and/or enhance the quality of the finite agricultural soils and other resources, such as air, water, and biodiversity, that form part of agroecosystems.

An agroecosystem perspective

Agroecosystems are communities of living organisms, together with the physical resources that sustain them, that are linked through their environment and managed in order to support crop and/or livestock production (adapted from Federal–Provincial Agriculture Committee on Environmental Sustainability 1990). Because of the many interrelationships among components within this complex and dynamic system, actions in one component affect other components and/or ecosystems.

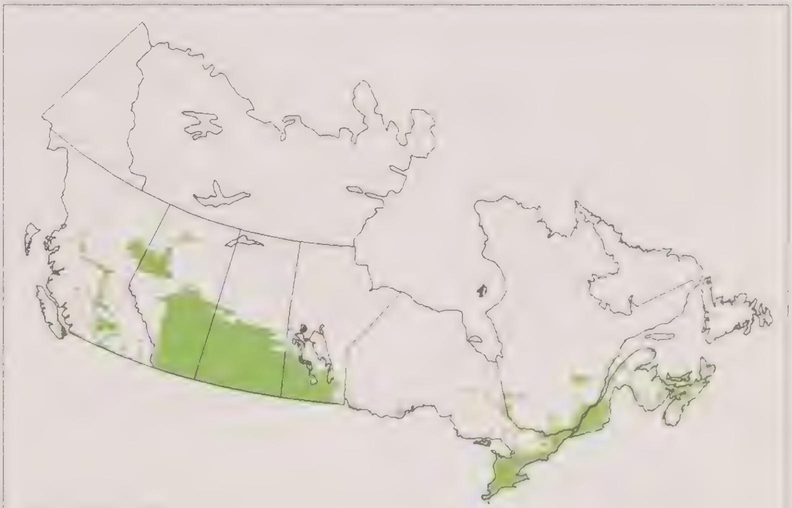
Farmers' decisions about management practices (e.g., decisions about land management and inputs such as fertilizers and pesticides) are influenced by their access to technology and by the economic and policy signals transmitted by the marketplace and governments. These management practices, in turn, affect the health of agroecosystems and, ultimately, the productivity and sustainability of agriculture.

Socioeconomic changes in Canadian agriculture

Canadian agriculture has been changing in response to social, economic, and technological forces. Figure 11.2 shows that the nation's finite supply of agricultural land supports an ever decreasing number of farms: between 1941 and 1991, the number fell by approximately half, while average farm size increased about two and a half times (Statistics Canada 1994a). Because only 8% of the farms occupy about 43% of all farmland, decisions taken by a relatively small proportion of farmers will determine whether sustainable practices are employed on almost half of Canada's farmland.

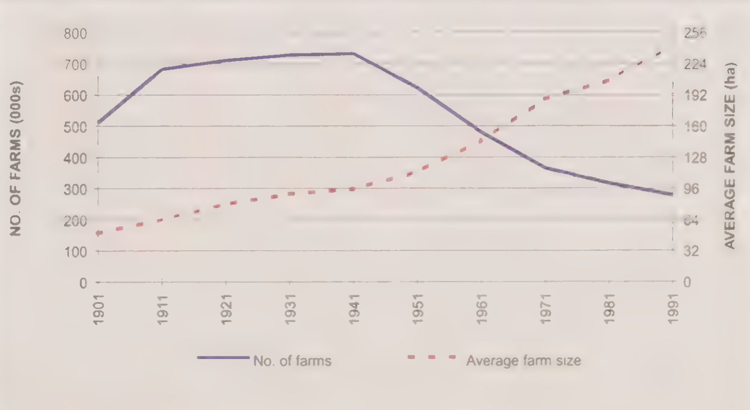
Between 1971 and 1991, the total area of farmland remained relatively constant, but there were important changes in agricultural land use. First, some agricultural lands were converted to nonagricultural uses, particularly near urban centres, whereas new lands brought into production tended to be of lower quality for agriculture. Second, agricultural land use has become more intensive, so that, on average, more is being produced per unit of land area. For example, between 1971 and 1991, the area of cropland increased by 20% (Fig. 11.3); cropland generally correlates with more intensive farming. Third, summerfallow area declined 27% over the same period.

Figure 11.1
Agricultural areas of Canada



Source: Acton (1995).

Figure 11.2
Change in number and size of farms in Canada, 1901–1991



Source: Statistics Canada (1994b)

The two principal commodity sectors in Canadian agriculture were meats (cattle, hogs, veal, and lamb), which contributed 27% to 1994 farm cash receipts, and grains and oilseeds (wheat, durum, oats, barley, flax seed, canola, soybeans, and corn), which contributed 30% (Canadian Federation of Agriculture 1995). There is, however, considerable regional variation, as illustrated in Figure 11.4.

Canada's agri-food exports have been increasing in recent decades. In 1993, 48% of the value of the country's agricultural production was exported. The Prairie provinces are more dependent on exports and interprovincial trade of agricultural products than are the eastern provinces, where the majority of the food produced is consumed domestically (Carter et al. 1989; R. Sopuck 1993). Consequently, farmers in the Prairie provinces continue to be highly sensitive to changes in international prices and food consumption trends. International trade agreements, such as the North American Free Trade Agreement and the World Trade Organization Agreement, present both adjustment challenges to the agri-food sector and opportunities to enhance exports. Both of these have important environmental and resource management dimensions that are not yet fully understood.

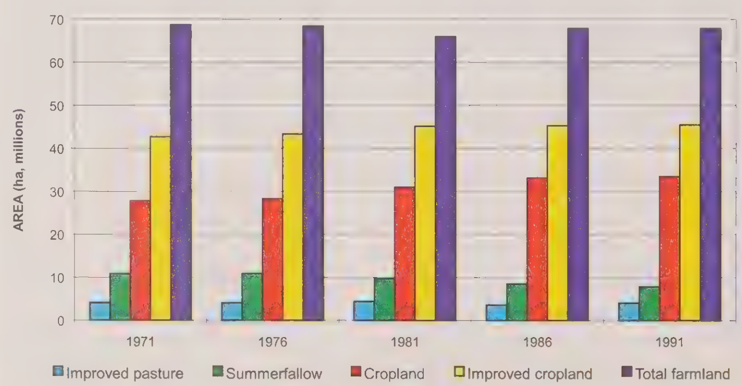
Agri-environmental issues

This section examines several issues that relate to the environmental sustainability of agroecosystems and updates information contained in the previous edition of *The state of Canada's environment* (Government of Canada 1991). In most cases, the information comes from studies or monitoring data in specific locations and not from comprehensive nationwide monitoring programs.

Soil quality

Soil quality is defined, in an agricultural context, as "the soil's fitness to support crop growth without resulting in soil degradation or otherwise harming the environment" (Acton and Gregorich 1995). Land use and land management practices affect soil quality. Some traditional practices, such as up-and-down slope cultivation, intensive row cropping, monoculture cropping, and fallowing, make the soil more susceptible to processes that reduce soil quality, through (1) loss of organic matter, (2) wind, water, and tillage erosion, (3) changes in soil structure, (4) salinization, and (5) contamination from chemicals used in crop production (Acton and Gregorich 1995).

Figure 11.3
The use of farmland in Canada, 1971–1991



Improved pasture is area improved by seeding, draining, irrigating, fertilizing, and brush or weed control, not including areas where hay, silage, or seeds are harvested.

Summerfallow is area that has been left idle (not worked) for at least one year.

Cropland is the total area on which field crops, fruits, vegetables, nursery products, and sod are grown; improved pasture and summerfallow are excluded.

Improved cropland is the sum of cropland, summerfallow, and improved pasture.

Total farmland is the total area of land operated, including improved cropland and unimproved land.

Source: Statistics Canada (1992a).

Soil organic matter levels

Organic matter is an essential component of soil. It stores and supplies plant nutrients, aids water infiltration into soil, retains carbon, and stabilizes soil (Gregorich et al. 1995). The amount of organic matter in soil varies widely, from 1–10% in most agricultural soils to more than 90% in wetlands where peat is accumulated. The optimum organic matter content of soil depends on local climate, the amount of clay present in the soil, and the soil's intended use (Gregorich et al. 1995).

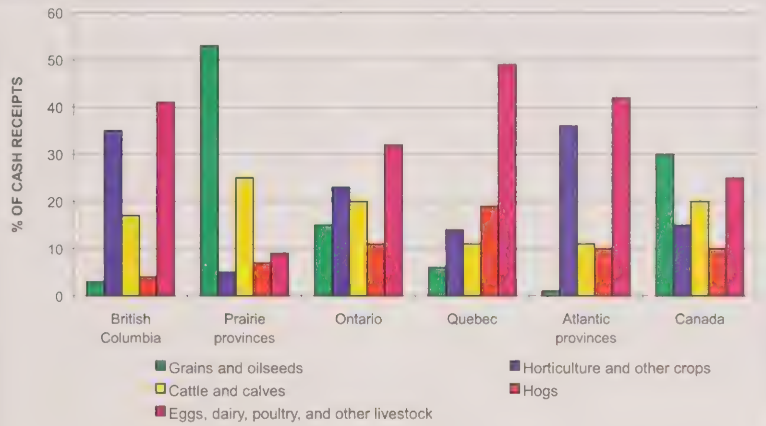
Cultivation of previously undisturbed forest or grassland soil to produce crops alters the natural plant–soil system, usually resulting in a decline in organic matter levels. Much of this decline occurs in the decade following initial cultivation. Recent research suggests that losses of soil organic matter in Canada's uneroded agricultural soils since initial cultivation are typically in the 15–30% range (Gregorich et al. 1995).

Comprehensive data on soil organic matter across Canada are lacking. Some trends regarding the effects of land use and farming practices on soil organic matter are available, however, for specific regions. "Evidence shows that soil organic matter levels are being maintained or increased in many Canadian croplands because of improved management. For example, long-term cropping experiments in the Prairie provinces suggest that levels of soil organic matter are holding steady, meaning that the amount of organic matter taken out of the soil in the form of crops is replenished by adding crop residues, manure and commercial fertilizers" (Gregorich et al. 1995).

Figure 11.5 indicates a 35% reduction in soil organic matter during the period 1910–1990 under historical management practices. This figure also illustrates a computer simulation of the potential for losing, conserving, or increasing soil organic matter levels under different soil management regimes. This simulation indicates that organic matter levels would (1) continue to decline to some steady state under conventional tillage without fertilization; (2) decline at a slower rate under no-till without fertilization; and (3) significantly increase over present-day levels using no-till with adequate fertilization (Gregorich et al. 1995).

Figure 11.4

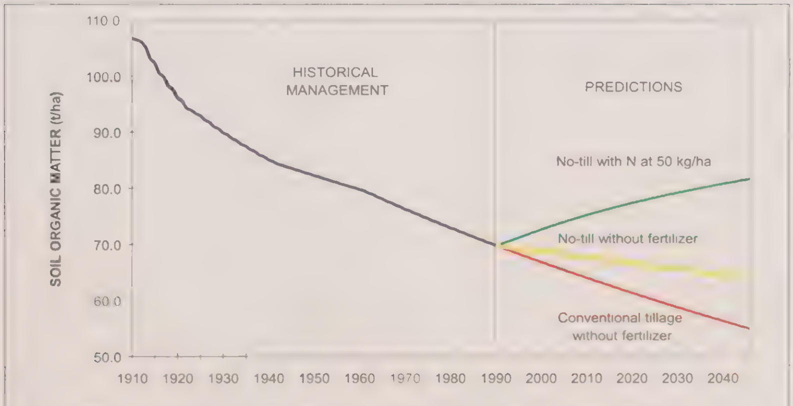
Regional variation in Canadian agricultural production; distribution of average of 1983–1992 farm cash receipts



Source: Compiled by Policy Coordination Division, Policy Branch, Agriculture and Agri-Food Canada, from Statistics Canada (1994c).

Figure 11.5

Soil organic matter levels under three management practices



Note: Predictions are computer projections of total levels of organic matter in the top 30 cm of a prairie soil under no-till with and without fertilizer and under conventional tillage without fertilizer.

Source: Gregorich et al. (1995).

Wind, water, and tillage erosion

Erosion is a natural process that can be accelerated by activities such as farming or forestry. Erosion of soil by wind and water is considered the most widespread soil degradation problem in Canada (Government of Canada 1991). Tillage erosion (the movement of soil downhill during tillage operations) is also now recognized as a factor contributing to soil erosion and degradation on rolling or hummocky land (Wall et al. 1995; D. Lobb and L. Ouellette, Eastern Canada Soil and Water Conservation Centre, personal communication). Loss of topsoil (the soil layer best suited to support life) reduces the ability of remaining soil to produce a crop by reducing its fertility and its ability to accept and store water and air (Acton and Gregorich 1995). Products of soil erosion can have detrimental effects if they are introduced into water bodies.

The inherent vulnerability of bare soil to erosion by wind and water is a function of a soil's texture, its structure, and the slope of the land. These characteristics have been surveyed, and Canada's agricultural land has been classified by its susceptibility to erosion (Wall et al. 1995).

The risk of soil erosion by wind is of concern in nearly all agricultural regions of Canada, but it is most extensive and damaging in the Prairie provinces. Here, inherent risk of wind erosion on bare soil is negligible to low on 37% of cultivated land, moderate on 29%, and high to severe on 36% (Wall et al. 1995).

The risk of soil erosion by water is also a concern in all of Canada's agricultural areas. The risk is greatest on land under intensive cultivation. The inherent risk of water erosion on bare soil is negligible to low on 63% of Canada's cultivated land, moderate on 17%, and high to severe on 20%. The Maritime provinces (80%), British Columbia (75%), and Ontario (50%) have the largest areas of cultivated land at high to severe inherent risk; the Prairie provinces have a low inherent risk of soil erosion by water (Wall et al. 1995).

The risk of soil erosion on agricultural land can be exacerbated or minimized depend-

ing on the cropping and land management practices used. Between 1981 and 1991, the risk of both wind and water erosion on agricultural land was reduced through changes in land tillage practices, reductions in summerfallow, changes in cropping patterns, and use of erosion control measures (Wall et al. 1995) (for details of conservation measures and their results, see the section on "Agriculture and sustainability").

Soil structure

Soils are especially vulnerable to structural degradation when they are fine-textured, wet, and low in organic matter content. Thus, the inherent vulnerability of soil to structural degradation varies across Canada. Land management practices that contribute to soil structural degradation include intensive tillage, row cropping, and insufficient rotation (Topp et al. 1995).

Soil compaction, one of the most recognized forms of structural degradation, occurs when soil particles are compressed, reducing the pore space between the particles. The main cause of soil compaction is repeated passes of heavy machinery over wet soil during tillage and harvesting (Topp et al. 1995). A 1986 study by the Science Council of Canada estimated that soil structural degradation due to compaction was reducing crop yields in Canada by 10% and was costing producers more than $130 million annually (Science Council of Canada 1986). The economic loss due to soil compaction was estimated to be greatest in Quebec, where 20% of the best farmland was compacted. Compaction was also found to be widespread in British Columbia. In southwestern Ontario, 50–70% of clayey soils had been adversely affected by soil compaction; three-quarters of this land was considered moderately compacted, and one-quarter severely compacted. The Atlantic provinces have naturally compacted subsoils and hardpans (hardened soil layers with greatly reduced porosity). Farming on moist soils in the region results in additional compaction. The Prairie provinces do not have a serious problem with soil compaction (Topp et al. 1995).

Soil salinization

Soil salinization (an excess of salts in the soil) restricts the amount of water a plant can withdraw from the soil, thus reducing the soil's capacity to produce crops. In contrast to soil erosion, which usually occurs on the surface, soil salinity most commonly affects soils at depth. The salinization of dryland soils is primarily a natural process and takes place where a high water table, high rate of evaporation, and soluble salts present in the soil system all occur together.

Any process that affects the soil–water balance, such as replacement of natural vegetation with crops and summerfallow, may alter the extent and degree of soil salinity. Summerfallow is commonly considered a major cause of soil salinization (Eilers et al. 1995). Recent long-term investigations, however, have not been able to correlate visual observed total salinity to crop–fallow rotations (Harker et al. 1995).

Although soil salinity is a continuing problem in some prairie soils, recent research on soil salinization shows that 62% of prairie agricultural land has less than 1% of its area affected by salinity, 36% has 1–15% of its area affected, and 2% has more than 15% of its area affected (Eilers et al. 1995).

Chemical contamination

Chemical contamination can affect the suitability of soil for various uses, including food production. A recent report on the contamination of agricultural soils concluded that "contamination of Canadian agricultural soils with pesticide and nonpesticide contaminants is not a serious problem. Currently used pesticides are not persistent in soil, and insignificant amounts are observed. But contamination of soil by heavy metals (e.g., cadmium, lead, zinc) is a concern because metals are persistent and may affect plant, animal and human health" (Webber and Singh 1995).

Heavy metals enter agricultural soils primarily through atmospheric deposition and application of soil amendments such as fertilizers, animal manures, and sewage sludge, which is applied to agricultural land as a source of organic matter and nutrients (Webber and Singh 1995).

Water quality

Agricultural activities can impact directly on surface water and groundwater resources. Surface water can be contaminated by sediment, nutrients, pesticides, and bacteria washed off agricultural land by surface runoff. Similarly, groundwater can be contaminated when rainwater, irrigation water, and snowmelt percolate through the soil and carry with them more nutrients or pesticides than the soil material can retain.

Crops obtain the nutrients that they require for growth from the soil, water, and air. To obtain economic yields and sustain soil fertility, extra nitrogen, phosphorus, and potassium must often be added in the form of commercial fertilizers or manure to replace the nutrients removed when crops are harvested. That which is not used by crops or absorbed or retained in the soil can migrate into surface water or leach into groundwater. Phosphorus is of concern because it can lead to eutrophication; nitrate can render water unfit for human consumption. Because an estimated 26% of Canadians rely on groundwater for domestic use and over 85% of the water consumed by livestock comes from the ground, protection of this resource from contamination is imperative (Hess 1986; Reynolds et al. 1995).

Factors influencing the amount and rate of leaching or movement of agricultural chemicals into surface water and/or groundwater include the type and intensity of agricultural practices, crop and land management practices, the type and amount of chemicals used, soil characteristics, and weather (Reynolds et al. 1995).

Water quality surveys and monitoring generally reveal that pesticides are usually found in concentrations below safe limits recommended in the Canadian Water Quality Guidelines. Nutrients and bacteriological contaminants are sometimes found in concentrations that exceed acceptable limits (Reynolds et al. 1995). Groundwater monitoring has not been car-

ried out for long enough or in enough detail to give a complete picture of the current status and trends of agrochemicals entering groundwater in Canada. However, selected examples from Canada's main agricultural regions provide some clues.

- In the Fraser and Okanagan valleys of British Columbia, significant amounts of agrochemicals, mainly nitrates, have been detected in the groundwater of several aquifers. Aquifers in south coastal British Columbia are particularly sensitive to contamination because of heavy winter rainfall. The Abbotsford aquifer, for example, is highly susceptible to contamination from a combination of extensive use of high-nitrogen poultry manure on raspberry and forage crops and climatic and soil conditions that promote leaching (Reynolds et al. 1995). Monitoring of nitrate concentrations since 1955 suggests average annual increases of 0.7 mg/L, and about 60% of the samples collected from a highly sensitive region of the aquifer exceeded the Canadian Water Quality Guidelines safe limit of 10 mg/L (H. Liebscher, Environment Canada, personal communication). Twelve different pesticides have also been detected in the aquifer: four at levels that exceed the Canadian Freshwater Aquatic Guidelines, and four (for which there are no Guidelines for Canadian Drinking Water Quality) that exceed Washington State water quality standards for groundwater (Liebscher et al. 1992; H. Liebscher, Environment Canada, personal communication). Nitrate leaching of significance has also been reported in an important aquifer near Osoyoos in the Okanagan Valley. Fertilizer use in orchards and septic effluent are suspected as the main nitrate sources (Reynolds et al. 1995; H. Liebscher, Environment Canada, personal communication).

- In the dry prairie region (southern Alberta and Saskatchewan), non-point source contamination of groundwater is rare, owing to the generally low intensity of agriculture (grain farming and low-density cattle grazing) and dry climate (Reynolds et al. 1995). The entry of agrochemicals into the subsoil and groundwater can be significant, however, under certain conditions. For example, at some locations in Alberta, application of feedlot cattle manure at the maximum recommended rates has resulted in soil and groundwater contamination by nitrate (Reynolds et al. 1995). In southern Manitoba, intensive agriculture and increased use of fertilizer and manure over the past 20 years have caused a buildup of certain agrochemicals in some areas. For example, elevated levels of nitrate have been found in the subsoils of fields that are heavily fertilized or manured, or both, and in cereal grains or horticultural crops. Although significant nitrate levels were not found in the groundwater, the potential for future contamination is high (Reynolds et al. 1995).

- In southern Ontario and Quebec, nitrate, bacteria, and the herbicide atrazine are the main agricultural contaminants. Nitrate contamination results primarily from a combination of fertilizer use, natural nitrate in the soil, and nitrogen compounds in rainwater. Bacterial contamination stems from high application rates of liquid manure. Atrazine contamination is largely due to intensive continuous corn cropping in the past (Reynolds et al. 1995). A recent Ontario-wide survey of 1 300 wells found that 37% of the farm wells tested contained coliform bacteria, fecal coliform, or nitrate exceeding Ontario Drinking Water Objectives. Nitrate at levels above the maximum acceptable concentration was found in 13% of the wells, and 7% had unacceptable concentrations of both coliform bacteria and nitrate–nitrogen (Goss and Fleming 1993).

- A study of 70 wells conducted in 1990 and 1991 in a sensitive region of Portneuf County, Quebec, revealed that 29 had nitrate–nitrogen levels in excess of 10 mg/L. Eighteen wells showed bacteriological contamination. Low levels of pesticides were detected in half of the wells, except for the pesticide aldicarb, used for insect control in potato production, levels of which exceeded the Canadian drinking water standard of 9 µg/L in three wells (Ministère de l'Environnement du Québec 1993).

- A study from 1973 to 1976 and in 1988 of 47 private groundwater wells in three intensive potato production areas of New Brunswick showed that a substantial portion of the wells in two of the three agricultural regions sampled had nitrate concentrations above the Canadian drinking water standard and that nitrate levels were correlated with the intensity of potato production (Richards et al. 1990). In the most intensive production area, 39% of the wells had nitrate levels above the standard. Nitrogen from both soil and fertilizer appeared to be the cause of the elevated nitrate levels.

- In Nova Scotia, a survey of farm wells in Kings County, where most of the province's potatoes and corn are grown, showed that 41% had detectable levels of pesticides, although none exceeded safe limits. Bacteria above the guideline levels were detected in 9% of the samples, and 13% exceeded the safe limit for nitrate (Reynolds et al. 1995).

In summary, the main impact of agriculture on groundwater and surface water quality is the entry of nitrate into these waters (Reynolds et al. 1995). "Water contamination by pesticides is less serious now than 10–20 years ago, because the pesticides in current use are generally less persistent and more specialized.... Public concern about potential health hazards of water contamination is expected to encourage the trend toward decreased use of agricultural pesticides and increased use of non-chemical pest controls" (Gregorich and Acton 1995).

Over the past five years, water quality has emerged as one of the key environmental issues facing agriculture (Agriculture and Agri-Food Canada 1995). Governments, researchers, and producers have responded with initiatives aimed at minimizing water quality risks. For example, of eight agricultural issues subject to federal–provincial agreements under the Green Plan, the water quality issue receives the most funding. Information on water quality initiatives is presented in the section on "Agriculture and sustainability."

Agriculture and biodiversity
The impact of agriculture on biodiversity — genetic, species, and ecosystem — has emerged as an important environmental issue. The discussion in this section is limited to the impacts of agriculture on native wild biodiversity. Biodiversity of domesticated species such as crop varieties is discussed in Chapter 14.

As noted in the 1991 report, *The state of Canada's environment*, "Generally speaking, the quantity and quality of wildlife habitat in Canada have been degraded by settlement and agricultural development. Although farmlands and rangelands do provide enhanced habitat for certain species (a number of which cause extensive damage to orchards and standing crops), others have declined as a direct result of agricultural expansion and production practices" (Government of Canada 1991). The modification of original ecosystems has led to a concern for their continued viability and the survival of the species that are found in these areas (Government of Canada 1991). For example, in the Prairies, much of the original habitat has been significantly altered, largely as a result of agriculture. Less than 1% of the original tallgrass prairie, 18% of the shortgrass prairie, 24% of the mixed-grass prairie, and 25% of the aspen parkland remain (Gauthier and Henry 1989).

Some current agricultural land management practices continue to alter biodiversity. For example, agricultural production systems with little crop rotation provide large areas of uniform habitat, thus reducing biodiversity. Water draining from agricultural fields can transport nutrients, eroded sediments, and pesticides to downstream areas, affecting aquatic biodiversity. Selective grazing of preferred forage plants can alter vegetation composition and have significant effects on wild species composition and abundance; range vegetation cannot maintain its integrity if grazing pressure is too high (Mineau et al. 1994).

Wetland ecosystems have been severely affected by agriculture. Eighty-five percent of the decline in Canada's original wetland area is attributed to drainage for agriculture (Rubec 1994). Changes such as this lead to a marked shift in vegetation and animal species composition. Many of the species affected are migratory; changes in habitat have a direct effect on the populations and life cycle of ducks, geese, swans, shorebirds, songbirds, and butterflies that make North America, Central America, and parts of South America their home.

Despite the historical impacts of agriculture on biodiversity, some farm practices can enhance wildlife habitat and promote biodiversity. Direct benefits can accrue from maintaining populations of pollinator species, pest predators, and soil fauna and from preserving habitats such as wetlands, which conserve groundwater and help protect against drought.

Many of the soil conservation practices being adopted by producers (described below in the section on "Agriculture and sustainability") also benefit wildlife. For example, the planting of shelterbelts, the planting of forage crops on marginal croplands, and planned grazing systems provide habitat to many forms of wildlife. The retention of soil organic matter also provides habitat to soil microorganisms, whereas integrated pest management techniques can reduce the risks from pesticides to nontarget species. By participating in habitat conservation programs such as the North American Waterfowl Management Plan (NAWMP), farmers have helped secure up to 261 000 ha of habitat on the Prairies (T. Coleman, Environment Canada, personal communication).

Greenhouse gases
Agriculture has the potential to act both as a source and as a sink for several of the atmospheric greenhouse gases that are believed to be responsible for climate change (see Chapter 15 for a more detailed discussion of atmospheric change). Agricultural activities relate to greenhouse gas concentrations in the following ways: (1) soils are an important natural source of and reservoir for carbon; (2) methane is emitted from livestock and liquid manure; (3) nitrous oxide is released from nitrogen fertilizers; and (4) carbon dioxide is released from the burning of fossil fuels in farming activities (Government of Canada 1994).

Agriculture contributed approximately 6.4% of Canada's total greenhouse gas emissions in 1994, or about 39 million tonnes of carbon dioxide equivalent. About 60% of this total (23.6 million tonnes) was methane from domestic animals and manure, about 29% (11.2 million tonnes) was carbon dioxide from fossil fuel use, and about 11% (4.2 million tonnes) was nitrous oxide from nitrogen fertilizer (unpublished data, Pollution Data Branch, Environmental Protection Service, Environment Canada). However, these statistics contain several gaps. For example, neither nitrous oxide emissions from soil or manure nor carbon dioxide emissions from soils are included. Conversely, the calculation omits any carbon dioxide sequestered in soils. Work is under way in Agriculture and Agri-Food Canada to improve the scope and accuracy of greenhouse gas emissions in Canadian agriculture.

Although fertilizer use has remained relatively constant since 1985, the amount of nitrogen in the total fertilizer mix increased from about 10% in 1960 to approximately 30% in 1985 (Government of Canada 1994). Nitrogen cycling in agricultural soils also generates nitrous oxide. This is probably the largest source of nitrous oxide from agriculture, and the least understood.

It is estimated that about 25% of Canada's total agricultural soil carbon has been lost since cultivation began (E. Gregorich, Agriculture and Agri-Food Canada, personal communication). Because losses of soil carbon are more rapid in the first years following cultivation of new lands, the carbon content of Canada's cultivated soils is believed to be near equilibrium. However, even small fluxes of carbon into or out of soils can represent large quantities of carbon dioxide when totalled across Canada.

Because soil carbon fluxes will influence the overall greenhouse gas balance for agriculture, efforts to retain and increase levels of organic matter in soils can play a positive role in sequestering carbon and offsetting carbon dioxide emissions from agriculture and other sources. In this regard, the increased use of practices such as conservation tillage and no-till are

encouraging from a climate change, as well as soil quality, perspective. Other agricultural practices that may result in future net reduction of greenhouse gas emissions include reduced summerfallow area, increased forage production, improved crop yields, reduced methane emissions from farm animals (through improvements in feeding technology and feed additives), improved efficiency of manure use, decreased fossil fuel use, and increased use of renewable fuel ethanol (Agriculture and Agri-Food Canada 1995).

Energy use

Agriculture is a direct consumer of energy for use in such activities as tilling, harvesting, heating, and ventilation. A 1990 study indicated that "Within the agri-food sector primary production accounts for 28% of the energy used; processing and packaging (22%), distribution (18%), and storage and preparation (32%). Mobile (transportation) fuels account for 57% of the energy consumed in primary agricultural production on the farm. An additional 25% is accounted for by fertilizers. On-farm energy consumption for primary agricultural production accounts for approximately 3% of Canada's total energy consumption" (Federal–Provincial Agriculture Committee on Environmental Sustainability 1990). The main environmental concern related to energy use in the agriculture sector is the consumption of fossil fuels resulting in greenhouse gas emissions. Expanded production and use of renewable fuels such as ethanol could have environmental benefits — resulting in lower net carbon dioxide emissions, for example.

Economic and environmental factors have provided incentives for developing management systems with lower inputs, whereas crop yields have continued to increase (Swanton and Clements 1994). Reduced tillage, new herbicides with lower application rates, and genetic improvements in plants in terms of resistance to disease and lower fertilizer requirements all have implications for reducing energy use and achieving sustainability of agroecosystems.

Agriculture and sustainability

Initiatives related to sustainability of agroecosystems have historically focused on stewardship of private on-farm resources, primarily land and soil. More recently, efforts have also expanded to address off-farm concerns from agriculture, such as water quality and biodiversity.

Sustainable land management

Sustainable land management is fundamental to achieving sustainable agriculture. An appropriate mixture of land management practices tailored to the conditions and needs of individual farms can provide multiple benefits for preserving soil health and productivity, minimizing water contamination, conserving wildlife habitat, and maintaining farm nutrient balances. Examples of such management practices include growing forage crops in rotations or as permanent cover, growing winter cover crops, planting shelterbelts, strip cropping, using buffer strips, and using conservation tillage techniques and contour cultivation.

Soil conservation practices

Over the past decade, producers, industry, and governments have made a concerted effort to reduce the extent of wind and water erosion on Canada's agricultural lands through the use of soil conservation practices (Wall et al. 1995). As illustrated in Figure 11.6, a significant proportion of Canadian farmers reported using one or more erosion control practices on their farms in 1991. It must be emphasized, however, that not all farms require erosion control and that some practices are applicable only in some regions and not in others. Among the key observations:

- over one-third of Canadian farms reported using a forage-based rotation system on some of their cropland;
- strip cropping was used on 8% of farms and 15% of cropland (Trant 1993);
- winter cover crops were used on 9% of farms and 10.5% of cropland (Trant 1993);
- 11% of farms reported using grassed waterways; and
- conservation tillage (including no-till) was used on 31% of land seeded (Fig. 11.7).

Figure 11.6

Percentage of farms reporting erosion control, 1991

Notes: 1991 was the first time that this type of information had been collected in the Census of Agriculture; therefore, there are no trends. A farm may use more than one erosion control practice or none at all.

Source: Statistics Canada (1992b)

Conservation or reduced tillage systems (where a portion or all of the crop residue is left on the soil surface) provide protection against erosion, reduce soil crusting, help retain moisture by trapping snow, and increase soil organic matter content. These systems appear to be the most cost-effective soil practice for general use across the country (see Box 11.1). The potential to reduce production costs has sparked much of the interest in these systems. The effectiveness of conservation tillage systems in reducing soil erosion is related to soil type, a good knowledge base on the part of the operator, and an effective management system that can respond to changes in pests that come with new tillage and planting regimes.

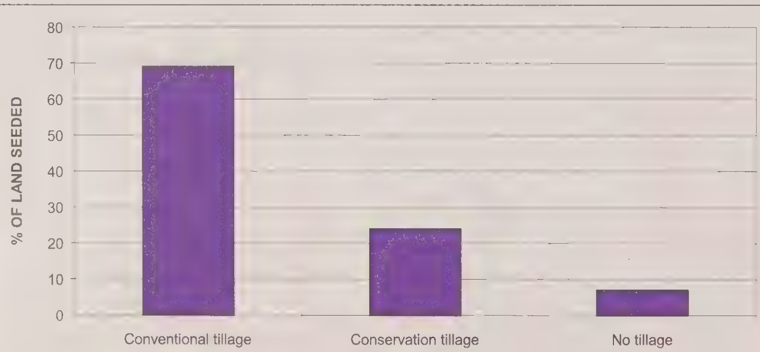
Erosion controls and changes in cropping, tillage, and water management practices have increased the amount of soil cover (amount of soil surface covered by crop residue) on agricultural land, resulting in a 10% decrease in the risk of both wind and water erosion in Canada between 1981 and 1991 (Wall et al. 1995). Changes in cropping practices and implementation of soil conservation practices (as reported in the Census of Agriculture) resulted in:

- just under a 7% decrease in the risk of wind erosion in the Prairie provinces between 1981 and 1991 (see Fig. 11.8); and
- an 11% decrease in the risk of water erosion across Canada between 1981 and 1991 (see Table 11.1) (Wall et al. 1995).

Despite the progress made, some agricultural lands remain at risk from erosion. It is estimated that under 1991 management practices:

- the tolerable annual limit for soil loss from wind erosion in the Prairie provinces was exceeded on about 15% (5 million hectares) of cultivated land; this includes about 750 000 ha in the high to severe erosion risk classes and the remainder in the moderate class (see Fig. 11.9);
- about 2% of cultivated land in the Prairie provinces is at high to severe risk of water erosion (see Fig. 11.10); and
- about 5% of southern Ontario soils are at risk of high to severe rates of erosion, and about 60% of southern Ontario's cultivated land requires increased use of conservation management practices (Wall et al. 1995).

Figure 11.7
Tillage methods used to prepare land for seeding in Canada, 1991



Conventional tillage: most of the crop residue (plant material remaining after harvest) is incorporated into the soil.
Conservation tillage: most of the crop residue is left on the soil surface to provide protection against erosion, reduce soil crusting, and increase the organic matter content of soils; also known as mulch tillage, minimum tillage, and reduced tillage.
No tillage: any system where soil is not disturbed between harvesting one crop and planting the next; includes direct seeding into stubble or sod; also known as zero-till.

Source: Statistics Canada (1992b); Dumanski et al. (1994).

Ontario and the Prairie provinces account for about 90% of Canada's cultivated land. Detailed estimates of erosion risk under 1991 management practices for the other agricultural regions of Canada were not available for inclusion in this report.

The adoption of appropriate conservation practices has also resulted in a decrease in the risk of salinization over the last 10 years. A recently developed soil salinity risk index, based on traditional concepts of cultivation and salinity relationships, shows that most Prairie farmland (61% in Manitoba, 59% in Saskatchewan, and 80% in Alberta) had a low risk of increasing salinity under 1991 farming practices (see Table 11.2). The remaining farmland in these provinces, however, had a moderate to high risk of increasing salinity under 1991 cropping practices (Eilers et al. 1995).

Nutrient use and management
Appropriate use and management of nutrients and their sources, primarily fertilizers and manures, are required to maintain soil productivity and minimize environmental risks from agriculture, such as contamination of surface water and groundwater.

Fertilizer application rates in Canada were at their highest in the mid-1980s and declined between 1985 and 1990. Based on available data, the following national trends are apparent:

- Application intensity declined from 0.22 t/ha in 1970 to 0.18 t/ha in 1990, despite increases in crop and livestock output (Statistics Canada 1994b).
- The percentage of Canadian farms using commercial fertilizer declined from 66% in 1985 to 59% in 1990 (Statistics Canada 1992b).
- The nutrient content of fertilizers applied has increased from about 20% in the 1920s to over 50% in the 1990s (Statistics Canada 1994b). The nitrogen content of the total fertilizer mixture went from 10% in 1960 to approximately 30% in 1985. Phosphorus and potassium con-

Box 11.1
Conservation farming boosts income

A survey of 80 farmers in southwestern Manitoba indicated that the most important factors influencing their decision to adopt conservation practices were potential profit and "a strong sense of maintaining their land in a state as good [as] or better than they found it. These are common characteristics in most if not all farmers. Farmers who become convinced that adopting conservation practices is a viable means toward those ends are likely to make changes in that direction" (Josephson 1992). The survey results showed income boosts averaging $32.78 per hectare per year among farmers who had adopted tillage reduction, forage production, grazing management, or land retirement methods known to protect soil and water resources and improve land for wildlife.

Planned grazing, tillage reduction, and forage establishment on uplands and the margins of wetlands increased net income when compared with traditional practices. Retiring land, modified fallow techniques (chem-fallow and underseed fallow), and the late cutting of forage (a technique designed to save the nests of ground-nesting birds) required incentives to remain profitable.

In the North American Waterfowl Management Plan target area, incentives were available for landowners to adopt the above-mentioned practices, but these payments were excluded from the analysis, which compared production-related income and expenses only. Government agricultural subsidy programs and the benefits that came from the control of soil erosion and improved wildlife habitat were not factored into the analysis either.

Significant income gains are predicted for southwestern Manitoba if these soil-conserving practices are adopted by all farmers to the same extent as the 80-farmer study group (T. Sopuck 1993).

In Alberta, a study of 250 fields representing 75 producers, conducted during the period 1988–1992, also demonstrated the economic benefits of conservation tillage. Results from this study demonstrated that there is a $6.42 per hectare advantage for zero-till over conventional tillage systems (Appleby 1993).

The only two inputs that changed much as farmers changed their tillage practices were the cost of herbicides and the cost of field operations (all trips across the field involving tillage, spraying, seeding, swathing, and combining). All other direct inputs, such as seed cleaning, were less affected by change in tillage. Indirect costs such as land were not affected by tillage changes. A breakdown of various costs involved for the three major tillage systems is shown in Table 11.B1.

Herbicide costs increased in conservation tillage systems. The results of the analysis show that these costs were $17.98 per hectare higher in zero-till operations than in conventional systems. Conversely, field operations were $11.12 per hectare lower with zero-till systems.

Table 11.B1
Costs of wheat production, by tillage system, 1988–1992

	Cost ($/ha)		
Type of cost	Conventional tillage	Reduced tillage	Zero-till
Herbicides	20.77	29.49	38.75
Fertilizer	40.06	33.91	35.15
Field operations	35.89	30.08	24.77
Fixed costs	29.00	29.42	29.12
Other	26.08	22.92	17.59
Total	151.80	145.82	145.38

Source: Appleby (1993)

tents have risen as well (Government of Canada 1991).

Regionally, fertilizer use trends are more diverse:

- Fertilizer use increased fivefold in the Prairie provinces between 1970 and 1990; the 1980–1990 increase was 23% (Statistics Canada 1994b). However, nutrient additions through fertilizers remain below nutrient removals from soils through crops. Figure 11.11 suggests that significant depletion of nitrogen and phosphorus in soils took place during the period 1965–1993; despite substantial progress made since 1965 in reducing the gap between nutrient additions and removals, the imbalance continues, especially in Saskatchewan and, to a lesser extent, Alberta.
- Between 1980 and 1990, in Ontario, both fertilizer use and application rates decreased (from 0.54 to 0.37 t/ha), whereas Quebec recorded a decrease in fertilizer use but an increase in application rate (from 0.42 to 0.47 t/ha) (Statistics Canada 1994b).
- Farmers in the Atlantic provinces, with the exception of Nova Scotia, continue to apply fertilizer at the highest average rates in the country; the application rates in tonnes per hectare for 1990 were 0.69 in Newfoundland, 0.59 in Prince Edward Island, 0.39 in Nova Scotia, and 0.56 in New Brunswick (Statistics Canada 1994b).

Internationally, nitrogen use intensity in Canadian agriculture is the lowest of the G-7 countries (Fig. 11.12) and is among the lowest of the Organisation for Economic Co-operation and Development (OECD) countries, owing mainly to the extensive nature of Canadian agriculture, the types of crops grown, and the high proportion of dryland area in Canadian agriculture that is less responsive to added fertilizer.

Manure is an important source of nutrients and organic matter for agricultural land. Approximately 37% of Canadian farms applied livestock manure to more than 2 million hectares of land in 1990

(Statistics Canada 1992c). Over half this area was in Quebec and Ontario. Not all manure produced on Canadian farms is applied to agricultural fields. Specialization and concentration of livestock production have created waste management problems that can affect soil and water quality.

Manure handling and storage have come under close scrutiny. Various methods to address problems include regulations, guidelines, and codes of practice under existing legislation (e.g., in British Columbia, Saskatchewan, Alberta, and Manitoba) and assistance to producers to improve manure storage and management (e.g., Quebec). Given the trends of increased livestock specialization and concentration, sound management of livestock and poultry manures will be essential to meet sustainability objectives.

Pesticide use and management

Trends in agricultural pesticide use are governed by farm type, local growing conditions, product prices, and crop selection. The majority of pesticides used in Canada (70%) are herbicides (Mineau et al. 1994). Nationally, the use of commercial herbicides appears to have declined since a peak in the mid-1980s (Fig. 11.13). In 1990, commercial herbicides were applied to approximately 21.5 million hectares of farmland. This is twice the area treated in 1970 but slightly less than that treated in 1985 (Statistics Canada 1992b). Insecticides or fungicides were applied to approximately 2.8 million hectares in 1990 (Statistics Canada 1992c).

The proportion of farmers using herbicides has decreased since 1985 — 49% of farms reported using herbicides in 1990, compared with 59% in 1985. The largest proportion of farmers using herbicides (68%) was in Saskatchewan; Newfoundland had the smallest, at 16% (Statistics Canada 1992b).

A 1993 survey in Ontario (Hunter and McGee 1994) indicated that pesticide use declined from 7 200 t of active ingredient in 1988 to 6 200 t of active ingredient in 1993 — a drop of 13.3%. The decline for the 10-year period 1983–1993 was 28.3%.

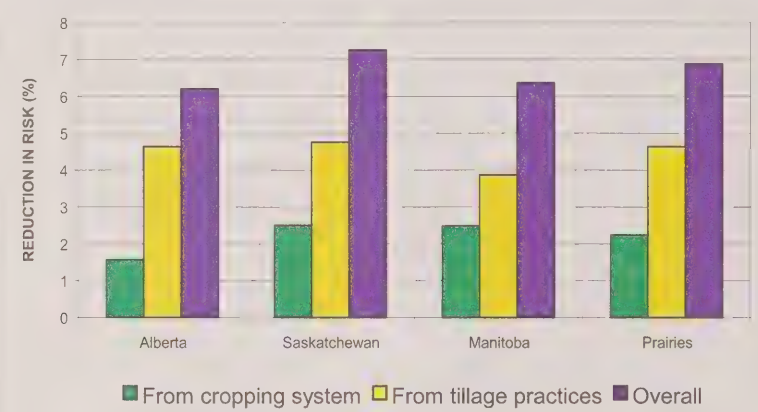
Overall, the data suggest that fewer farmers are applying agrochemicals to a smaller land area and that fewer pesticides are being applied per unit of crop output. Newly developed pesticides are more selective, less persistent, and less toxic to nontarget organisms (Agriculture and Agri-Food Canada 1995). Further information on pesticides, the environmental concerns associated with their use, and pesticide sales in Canada is given in Chapter 13.

Changes in energy efficiency of crop production

Agriculture has become increasingly dependent on inputs, such as fertilizers and pesticides, and on mechanized technology; however, energy requirements have not increased proportionally. Energy requirements related to farming practices are less, even at intensive levels of production (Lobb 1989; Bonny 1993). Research on individual crop yields in Ontario between 1975 and 1991 showed that energy use per tonne of crop produced

Figure 11.8

Reduction in wind erosion risk in the Prairie provinces, 1981–1991



Source: Wall et al. (1995).

Table 11.1

Reduction in water erosion risk per hectare, 1981–1991

Province	Cultivated land in 1991 (ha, millions)	Erosion risk reduction per hectare (%) Resulting from cropping practice	Resulting from tillage practice	Total
Prince Edward Island	0.16	–9	3	–6
New Brunswick	0.12	2	4	6
Nova Scotia	0.11	–3	3	0
Quebec	1.65	3	3	6
Ontario	3.48	10	11	21
Manitoba	5.06	6	9	15
Saskatchewan	19.17	5	3	8
Alberta	11.06	5	8	13
British Columbia	0.61	7	10	17
Canada	41.42	5	6	11

Source: Wall et al. (1995).

declined by about 50% for both grain corn and soybeans (Swanton and Clements 1994; S. Murphy, Department of Crop Science, University of Guelph, personal communication).

The achievements in energy efficiency are due to improved genetics and crop and livestock productivity, greater use of no-till agriculture, and improved energy efficiency in farm buildings and machinery. Improved energy use efficiency is consistent with the objectives of environmentally sustainable agriculture.

Nontraditional agricultural activities
Farmers are continually looking for new and innovative ways to diversify and achieve sustainability within the agroecosystem. Nontraditional activities, such as organic farming (reliance on a management system using natural soil-forming processes and crop rotation schemes rather than synthetic inputs), alternative livestock production (raising of nonnative species and domesticated native species), and agroforestry (combining the production of trees and shrubs for economic purposes with agricultural plants and/or animals in the same land area), are gaining popularity (Agriculture and Agri-Food Canada 1995).

Recent initiatives to promote agroecosystem sustainability
Since the late 1980s, partnerships, program and policy reform, and research initiatives have been launched by governments, industry, and farmers to promote environmental sustainability within agriculture. These initiatives address issues at the national, provincial, regional, local, and individual farm level; selected examples are outlined below.

Partnerships
The National Soil Conservation Program was a program jointly funded from 1989 to 1993 by the federal and provincial governments under accords and agreements. It had two main objectives: to encourage appropriate soil use and management in order to sustain long-term soil productivity, and, in western Canada, to encourage economic diversification where applicable. The five basic program elements were awareness, research, soil survey and monitoring, on-farm technical and financial assistance, and permanent cover or land use adjustment. Overall, this program was effective in increasing awareness of soil conservation issues and solutions within the agriculture sector and in stimulating action and further research. The direct involvement of producers and producer groups was a key to its success.

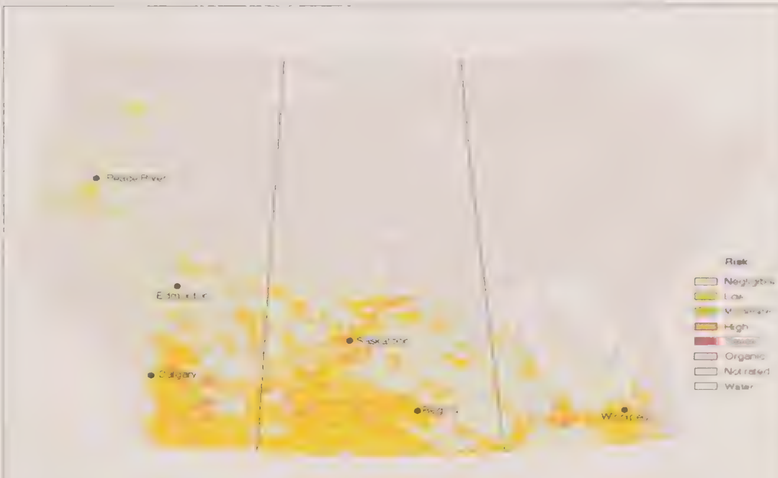
The Permanent Cover Program was a five-year program (1989–1994) that was offered to farmers in the Prairie provinces and the Peace River region of British Columbia. The main objective was to convert marginal lands under cultivation (Canada Land Inventory classes 4, 5, and 6) to permanent forage or tree cover. Under this program, about 15 000 farmers converted approximately 522 000 ha of marginal, erosion-prone land from annual crops to permanent cover under 10- or 21-year contracts (see Chapter 4).

The Permanent Cover Program is being integrated with the NAWMP in areas of the Prairie provinces with high waterfowl potential. By participating in habitat conservation programs such as the NAWMP, farmers have helped secure up to 261 000 ha of waterfowl land (71 000 ha of wetlands and 190 000 ha of grassed land) (T. Coleman, Environment Canada, personal communication). See Chapters 4 and 10 for more information on the NAWMP.

The sustainable agriculture component of Canada's Green Plan is providing funding for the 1992–1997 period to assist the transition to more sustainable farming practices. It builds on the National Soil Conservation Program by broadening the scope to encompass the full range of environmental sustainability issues and involving stakeholders as partners in program design, delivery, and funding. The largest share of the funding is being allocated under federal–provincial–territorial cost-shared agreements that have been put in place to address issues of regional concern.

One initiative under this program is the development of environmental farm planning. Farmers assess their own farms to highlight their environmental strengths, identify areas of concern, and set realistic goals to improve environmental conditions. In Ontario, the idea for farm plans

Figure 11.9
Risk of wind erosion in the Prairie provinces under 1991 management practices



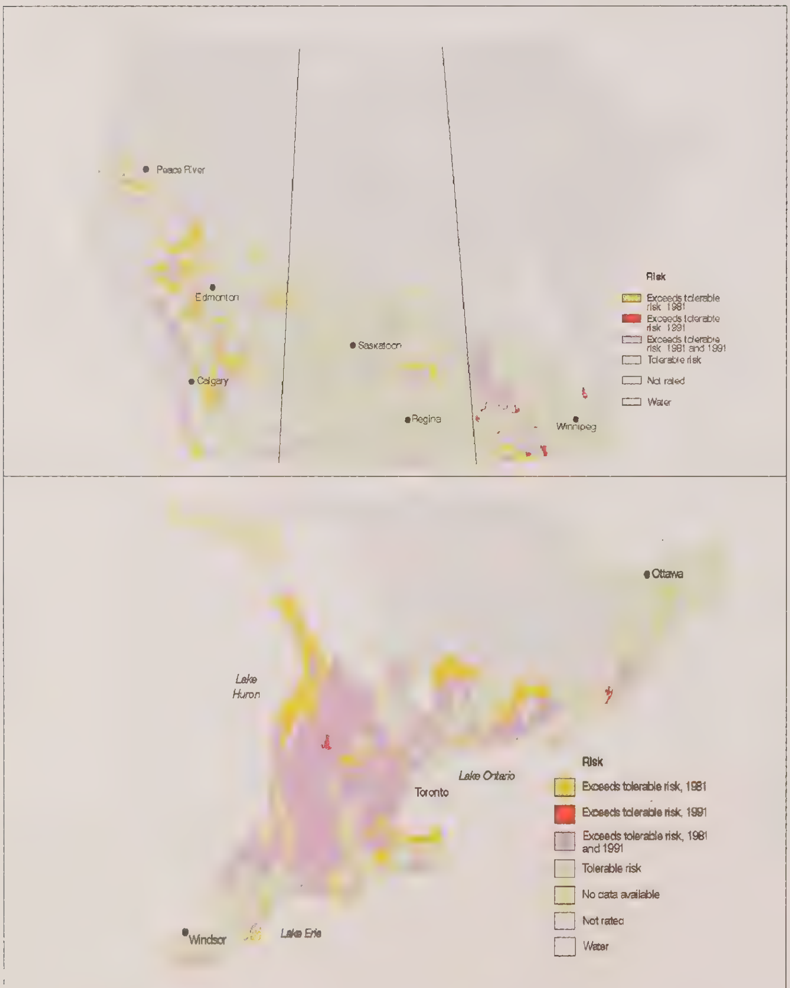
Note Management practices based on 1991 Census of Agriculture
Source Wall et al (1995)

originated with the farm community; up to 12 000 plans are projected to be completed by 1997. Similar programs have been initiated in several other regions of the country. In addition to efforts under various programs, many farmers have voluntarily organized themselves into various associations and societies that have in recent years been aimed specifically at environmental objectives.

Program and policy reform

A consultative process involving Agriculture and Agri-Food Canada, provincial governments, producers, industry, and other stakeholders has developed an updated National Environment Strategy for Agriculture and Agri-Food (Agriculture and Agri-Food Canada 1995). This strategy reviews the agriculture and agri-food sector's involvement in protecting the environment and assesses progress towards environmental sustainability. Emerging environmental challenges are identified, and approaches to resolving issues and seizing opportunities are provided. Three major categories of challenges are identified for the agriculture and agri-food sector: resource-based, management, and marketing and trade. The resource-based challenges (land, water, atmospheric, genetic, and energy resources) have received most of the attention from government and producers. Management challenges include waste, manure, packaging, biotechnology, pest management, environmental liability, nontraditional agricultural activities, international agreements, biodiversity, and public perception of the agriculture and agri-food sector.

Figure 11.10
Risk of water erosion in the Prairie provinces and southern Ontario, 1981 and 1991



Note: "Tolerable risk" refers to soils that are at risk of erosion at a rate that is tolerable for sustainable crop production under the most common management practices.
Source: Wall et al. (1995).

The National Agriculture Environment Committee was established in 1994. Agricultural producers were the main force behind the establishment of this committee, whose primary purpose is to establish national proactive strategies on environmentally sustainable agriculture issues. It provides a forum through which regional and local producer groups can share knowledge, identify courses of action, and work towards solutions in a coordinated fashion.

Environmental reviews of federal government policies and programs are conducted to integrate environmental considerations into the policy development process. Recently, Agriculture and Agri-Food Canada completed environmental assessments of various programs, including the Gross Revenue Insurance Program, the Net Income Stabilization Account, and Crop Insurance. The evaluations determined that these programs had no significant environmental impacts. Minor and localized adverse impacts on wildlife habitat were identified in the short term for the Gross Revenue Insurance Program and the Net Income Stabilization Account. These adverse impacts could become moderate to major, on a localized basis, if measures are not taken to preserve wetlands (Environmental Management Associates 1993a, 1993b; Agriculture Canada 1994). Reforms to farm safety net programs are moving towards whole-farm safety nets, under

which payments are not tied to any specific commodities. Environmental benefits, such as more appropriate land uses, are expected from these broader safety net programs.

Research

Research into the sustainability of agroecosystems is under way in various areas — for example, in developing disease- and pest-resistant crop varieties, reducing pesticide use, developing integrated approaches to pest management, and improving the efficiency of animals (through breeding and nutrition), resulting in less manure and better use of forage and grain. Research is also under way to improve understanding of agriculture's role in the carbon–methane–nitrogen balance and to develop more efficient fertilizer application technology and innovative approaches to manure management, with a major focus on the impacts of agricultural practices on water quality.

A recent example of cooperative research in agriculture is a pilot project launched in April 1994 by the Research Branch of Agriculture and Agri-Food Canada. Under this project, research and development are being done in a 50/50 partnership with industry. A total of $2 million was allocated for 1994 to launch this program, with larger amounts projected for subsequent years (Goodale 1994).

The data and information base on the environmental sustainability of agriculture continues to improve. Agriculture and Agri-Food Canada is developing a modelling capability to quantify the impact that agriculture can have on the environment as it responds to changing market conditions and policies. The Soil Quality Evaluation Project of Agriculture and Agri-Food Canada, completed in 1995, culminated in a major national assessment of the health of Canada's agricultural soils. Moreover, the department's ongoing benchmark site farm project will enable intensive study of soil quality and management factors at specific sites across Canada. The development of agri-environmental indicators will build on and broaden this knowledge base (McRae 1995). They will provide a means to evaluate agriculture's environmental sustainability, provide information on key trends, and facilitate the integration of environmental considerations into the decision-making process related to agriculture. Work on these indicators is ongoing, and the initial phase will be completed by 1998.

Conclusion and outlook

The foregoing discussion has highlighted some of the changes in Canadian agriculture over the past decade. Pressures to remain competitive in national and international markets continue to intensify, but with these come the stimulus and opportunities to respond in innovative and creative ways. Reductions in financial assistance under federal–provincial income support programs will result in more self-reliance and responsiveness to market signals. International markets are both a challenge and an opportunity. Some of the most effective farmer-driven innovations and developments in conservation farming systems have been motivated as much or more by economic signals to adopt new management systems and technologies as by stewardship interests.

This review has looked at what is known about changes in environmental quality associated with selected agri-environmental issues. Although the information base has improved since 1991, there remains a continuing shortage of data to monitor trends in agroecosystem health and productivity. In the absence of these data, it is difficult to assess comprehensively the extent to which public and private investments in sustainability activities are achieving the desired ends.

In this component, as in other parts of this report, the benchmarks used to interpret the significance of environmental change are the requirements for sustainability as outlined in the World Conservation Strategy: maintenance of life support systems, preservation of biological diversity, and maintenance of the productive capacity of species and ecosystems.

How successful has the agriculture sector been in meeting these requirements for sustainability, and where are the shortfalls?

Progress has been made towards preserving biological diversity and maintaining the productive capacity of species and ecosystems through the increased use of sustainable land management practices: in 1991, conservation tillage (including no-till) was used on about one-third of Canada's cultivated land; there was a 27% reduction in the area of land in summerfallow in the 20-year period between 1971 and 1991; both the area treated with herbicides and the number of farms using herbicides decreased between 1985 and 1990. Programs such as the Permanent Cover Program, under which half a million hectares of marginal, erosion-prone land in the Prairie provinces and the Peace River region of British Columbia have been converted from annual crops to permanent cover, help ensure that the use of land is compatible with its inherent capacity. The NAWMP, under which over a quarter of a million hectares of habitat in the Prairie provinces have been restored and enhanced for wildlife, also supports the maintenance of biological diversity and productive capacity of species and ecosystems.

Despite these encouraging trends, concerns about the sustainability of agro-

Table 11.2
Land at risk of increasing salinity, assessed using a salinity risk index

	% of land at risk		
	Low risk	Moderate risk	High risk
Manitoba	61	25	14
Saskatchewan	59	34	7
Alberta	80	17	3
Prairie region	66	27	7

Source: Eilers et al. (1995).

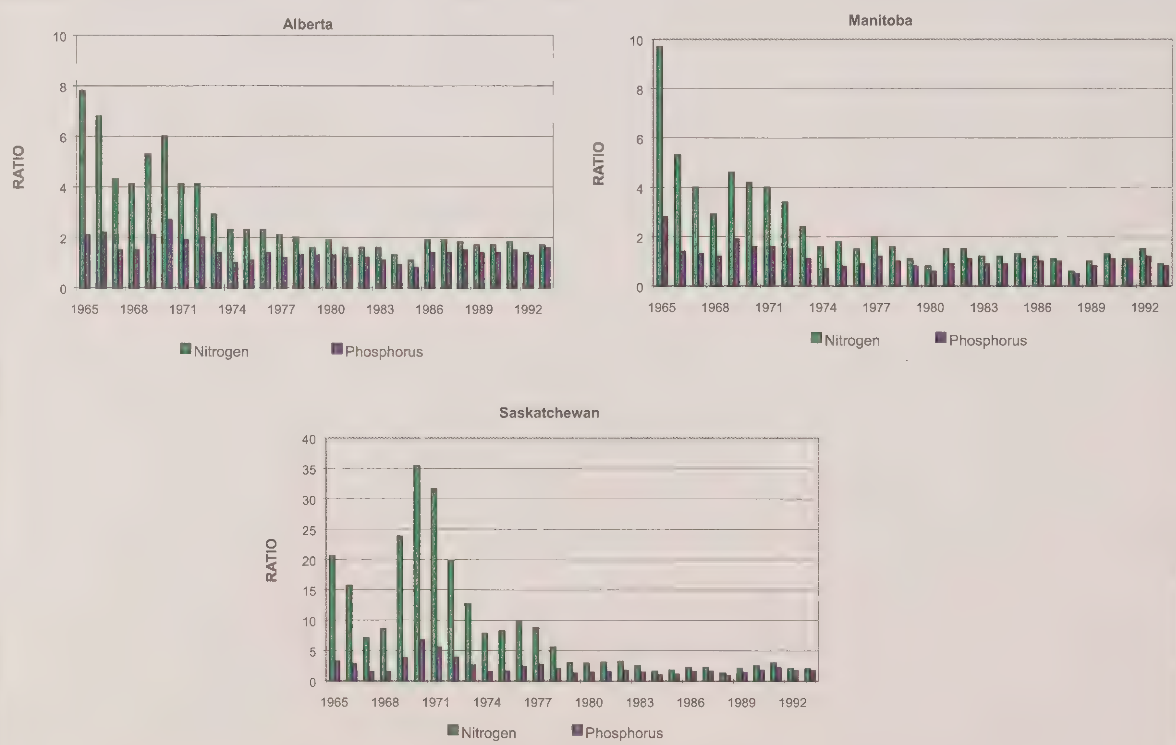
ecosystems remain. In some regions, agricultural lands remain at high risk of degradation from wind and water erosion, salinization, soil compaction, and organic matter loss. Nitrate is found in virtually all groundwaters in the agricultural regions of the country; levels are usually below recommended safe limits, but areas of intensive agriculture, such as south coastal British Columbia, the Maritime provinces, and areas under heavy manure application or irrigation, are prone to levels above safe limits. Other agricultural contaminants such as pesticides and bacteria have also been detected in certain areas. Thus, the protection of water quality as an essential component of life support systems represents an important challenge for Canadian agriculture.

Sustainable agriculture implies the use of resources to produce food without impairing the natural resource base upon which such production depends. The 1995 report on the health of Canada's agricultural soils (Gregorich and Acton 1995) summarizes the situation as follows: "The use of conservation farming methods has increased over the past 10 years. As a result, some agricultural areas are improving in quality and becoming less susceptible to erosion and other damaging forces. For example, levels of organic matter have increased in some areas, the risk of erosion has decreased nearly everywhere in the country, and the risk of salinization has decreased in the Prairie provinces. However, this general improvement is a small one overall, and does not apply to all soils. On the other hand, it provides proof that the health of our agricultural soils can indeed be maintained and even improved with the right care."

As understanding about the environmental impacts and opportunities of Canadian agriculture increases, as techniques evolve for more precise application of chemical

Figure 11.11

Ratio of nitrogen and phosphorus removed by crop harvest to nitrogen and phosphorus added by fertilizers for Alberta, Manitoba, and Saskatchewan, 1965–1993[a]



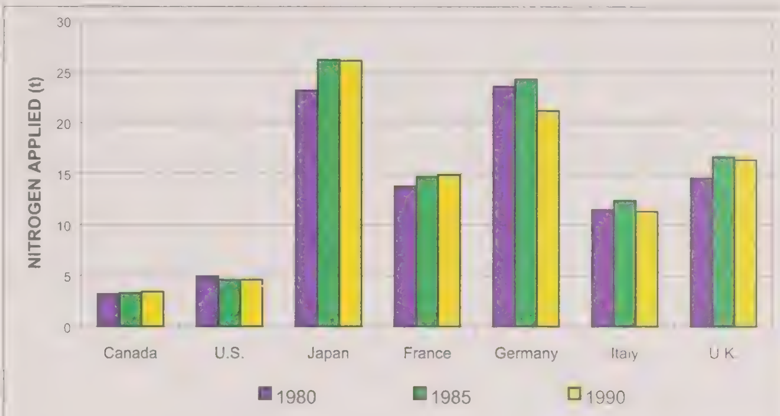
[a] Assumes nutrient removal by grain only, i.e., straw is returned to soil.

Example: In 1992, for Saskatchewan, 622 816 t of nitrogen were removed by crop harvest and 309 679 t of nitrogen were added with fertilizer; the ratio of nitrogen removed to nitrogen input was 2.0. The corresponding figures for phosphorus were 245 773 t removed, 145 821 t added; the ratio of removal to addition was 1.7.

Source: Doyle and Cowell (1993); updated with information from L. Cowell, private consultant, personal communication.

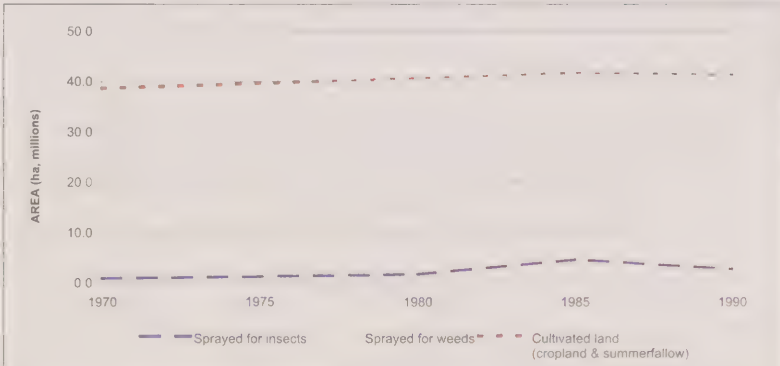
inputs, and as other conservation methods are perfected, the potential to avoid adverse environmental impacts from farming operations will increase. Ultimately, the responsibility for ensuring that the goal of sustainable agriculture is achieved has to be shared by farmers, the agri-food industry, government, and consumers. Cooperation and partnerships between the various groups will be critical to ensure the long-term sustainability of both agriculture and the environment.

Figure 11.12
Amount of nitrogen applied per square kilometre of agricultural land, G-7 countries



Note: This represents nitrogen from fertilizers and from livestock manure.
Source: OECD (1994).

Figure 11.13
Area sprayed for insects and weeds, 1970, 1980, 1985, and 1990



Source: Statistics Canada (1992b, 1992c).

Forestry

Introduction

Canada contains 418 million hectares of forestland (42% of the country's total area). Of the 245 million hectares that are capable of producing timber, about 119 million hectares are managed for timber production. An estimated 50 million hectares (12%) of forest are protected from harvesting by policy or legislation. Provincial governments are responsible for managing 71% of the nation's forests, whereas the federal and territorial governments oversee 23%. Six percent of Canada's forests are on property belonging to more than 425 000 private landowners.

In 1994, sales of Canadian wood and paper products totalled $59 billion, and the industry continued to be Canada's largest foreign exchange earner, exporting $32.4 billion of forest products. Its net contribution to Canada's balance of payments is about the same as the aggregate of all mineral fuels, ores, chemicals, metals, and agricultural products (R. Côté, Canadian Forest Service, Natural Resources Canada, personal communication).

Also in 1994, the forest industry directly and indirectly employed 880 000 workers, or 1 out of every 15 workers in the Canadian labour force. Although there are year-to-year fluctuations related to market conditions, the forest industry employs about the same number of workers as it did 10 years ago. A report prepared jointly by industry, labour, and government forecasts that employment in the pulp and paper industry will decline by 15 000–20 000 over the next decade. Today, 340 communities across the country rely on the wood products industry for their livelihood (Natural Resources Canada 1995a).

This component of Chapter 11 explores the linkages between the industrial forest sector and the forest ecosystem. It should be noted that the impacts of forest management activities cannot be isolated from other factors such as climate change and the long-range transport of airborne pollutants. A more comprehensive discussion of forest ecosystems that looks at these factors and linkages with nonforested ecosystems and other sectors is found in the regional ecozone chapters and the appropriate national issue chapters.

Certain forest issues, such as clear-cutting, are contentious. The intent here is not to justify one viewpoint over the other but to provide status and trend information as a basis for further discussion on the sustainability of forest ecosystems.

Box 11.2
Selected disturbance trends within five of the forested ecozones of Canada

Pacific Maritime

- *Moderate to severe pest infestations have been minimal.*
- *Harvesting has surpassed wildfire as the major disturbance.*
- *The total area of harvest remains small, although the volume per hectare extracted is the highest for all of Canada. Area has increased from approximately 10 000 ha harvested in 1920 to a current 50 000 ha in 1993 — 5% of the total for Canada.*

Montane Cordillera

- *A major Mountain Pine Beetle infestation, affecting 500 000 ha, occurred in the mid-1980s. Current infestation covers less than 50 000 ha.*
- *The area burned by wildfire has decreased significantly since 1930, from more than 150 000 ha to less than 50 000 ha per year.*
- *The annual area harvested began to increase substantially in the 1960s and now (in 1993) approximates 150 000 ha — 15% of the total for Canada.*

Boreal Plains

- *A major defoliation of 7–9 million hectares by the Forest Tent Caterpillar occurred in the late 1970s. Recent defoliation has been minimal.*
- *The annual area burned between 1930 and 1980 has been generally under 200 000 ha. Since the 1980s, the annual area burned has fluctuated between 300 000 and 400 000 ha.*
- *The annual area harvested has risen steadily from under 20 000 ha in 1920 to 76 000 ha in 1993 — 8% of the total for Canada.*

Boreal Shield

- *Major cycles of Spruce Budworm infestation occurred in the 1940s, 1950s, 1970s, and early 1980s. In 1974, 50 million hectares were infested. Current infestation covers less than 10 million hectares.*
- *Since 1976, the Forest Tent Caterpillar has had two major cycles of infestation: the late 1970s and the late 1980s to early 1990s, when the area infested peaked at close to 20 million hectares.*
- *The annual area affected by fire has ranged between 200 000 ha (1959) and 1 million hectares (1989).*
- *The annual area harvested increased from over 200 000 ha in 1920 to approximately 470 000 ha in 1993 — 48% of the total for Canada.*

Atlantic Maritime

- *Major cycles of Spruce Budworm defoliation occurred in the 1940s, 1950s, 1970s, and 1980s, peaking in 1981, when over 10 million hectares were defoliated.*
- *Defoliation by the Forest Tent Caterpillar has been on the increase recently in New Brunswick, affecting 200 000 ha. The only recorded previous outbreak was in the early 1980s, when over 1 million hectares were affected.*
- *An estimated 50% of the harvest in the 1970s and 1980s was salvage logging after infestation.*
- *The annual area burned is minimal owing to intensive fire suppression.*
- *The annual area harvested increased from 88 000 ha in 1920 to approximately 200 000 ha in 1993 — 20% of the total for Canada.*

Source: National Forestry Database, Canadian Council of Forest Ministers; ESSA Technologies Ltd. (1993); Environment Canada (1995a).

Influence of natural processes

Insect and fire disturbances are the most widespread and, in most parts of the country, the most significant of all the natural disturbances affecting forest structure and condition (Box 11.2). Windthrow is regionally significant. As an example, major wind damage occurred to the forests of New Brunswick in 1994, when thousands of hectares of forest were destroyed in one windstorm (see Chapter 7).

Insect and disease outbreaks and fire are integral components of dynamic and healthy forest ecosystems. When they are severe, however, they also damage commercial timber, wildlife, tourism areas, and private property. In the managed or commercial portion of the forests, resource managers strive to protect commercial forests through activities such as fire suppression, use of pesticides, and silvicultural methods that reduce the occurrence and extent of damage to the resources and other aspects of the forests that people value. These actions affect or become substitutes to natural disturbances, producing unknown ecological consequences.

Insects

Every year, insects defoliate millions of hectares — or an average of 4% — of Canada's forests (Fig. 11.14). The occurrence and distribution of tree diseases are often related to the occurrence and distribution of insect infestations. Such infestations weaken affected trees, allowing disease to take hold. Over the past 15 years, total depletions of commercial forests owing to insects and disease have equalled approximately one-half the total area harvested over the same period (Natural Resources Canada 1995a). The predominant insects include Eastern Spruce Budworm, Jack Pine Budworm, Eastern Hemlock Looper, Western Hemlock Looper, Mountain Pine Beetle, and Forest Tent Caterpillar.

The severity of infestation depends on the age of stand, causal insect, and frequency of occurrence. For example, Mountain Pine Beetle can kill Lodgepole Pine with one major infestation, whereas Hemlock Looper may take two or three successive

years of infestation in a given area to cause large-scale mortality.

Cycles of insect infestation are natural and continuing (Fig. 11.14). Spruce Budworm has been the dominant insect of damage, particularly for eastern Canada, over the last 30 years. Some researchers argue that logging and associated practices influence insect outbreaks (Swift 1993; Harding 1994). For example, in the interior Douglas-fir forests of British Columbia, the combination of reduced species mix (owing to selective logging for specific species) and fire exclusion (which has favoured the growth of certain tree species over others) has created a highly favourable environment for Spruce Budworm (Maclauchlan 1992).

Forest management accounts for approximately 2% of sales of all pest control products sold in Canada. In contrast, agriculture accounts for 80% of total sales, whereas domestic and industrial users account for the remaining 18%. Two main types of pesticides are used in forest management: insecticides used for insect control, primarily against Spruce Budworm and Hemlock Looper, and herbicides used against competing vegetation. Insecticides are used to mitigate damage in stands and protect them until they are harvested. Herbicides are discussed in more detail under the "Renewal" section.

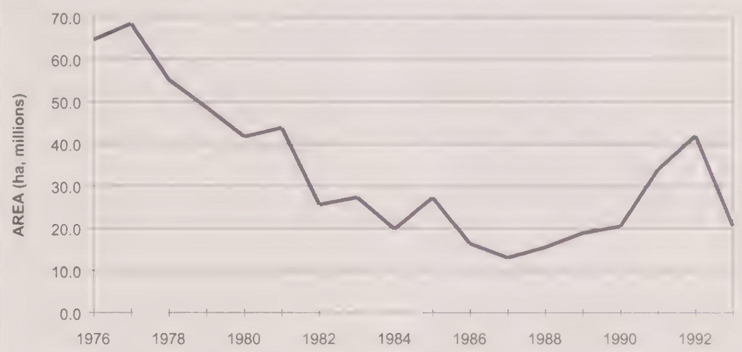
From 1982 to 1993, the area of insecticide treatment fell from 3 million hectares to 256 000 ha, reflecting a decline in Spruce Budworm populations (Fig. 11.15). Two-thirds of the area treated in 1993 involved the use of the biological insecticide Bt (*Bacillus thuringiensis*). Bt is expected to be the preferred insecticide for the foreseeable future. Prince Edward Island, Nova Scotia, Yukon, and the Northwest Territories have not used insecticides in forest management for several years. Manitoba ceased use in 1991, and Quebec in 1993. New Brunswick was the only province in 1993 to apply the chemical fenitrothion, aerially spraying 87 000 ha to combat the Spruce Budworm. The use of fenitrothion is down dramatically from the late 1980s, when 500 000 ha were sprayed within the province. This decrease (a similar drop in the use of Bt also occurred) is related directly to the decline in area infested by Spruce Budworm.

Wildfires

Many forest species depend on the regular occurrence of fire to regenerate. Lightning is the major cause of forest fire. The impact of fire, however, can be modified or eliminated by human actions. Long-term control of fire alters the natural cycles of forest ecosystems. As an example, fire suppression to preserve Red Pine and Eastern White Pine stands in eastern Canada may, in fact, cause changes in species composition. Recurring fires perpetuate these pine ecosystems, which, without fire, evolve into ecosystems characterized by species less reliant on fire for regeneration (McRae et al. 1994).

Figure 11.14

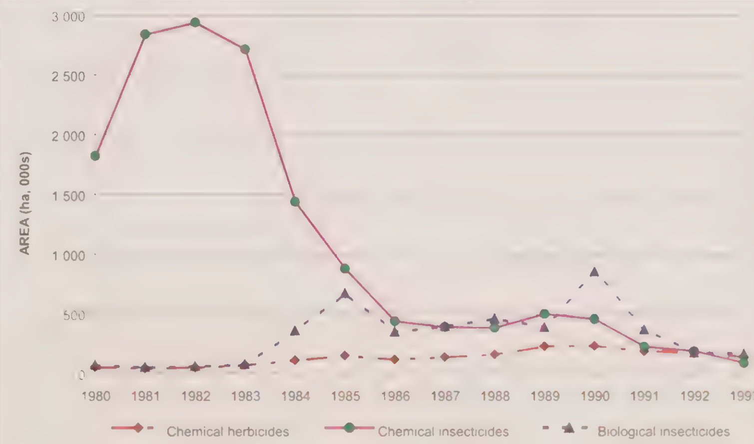
Annual area of moderate to severe defoliation by insects, 1976–1993



Source: National Forestry Database, Canadian Council of Forest Ministers.

Figure 11.15

Trends in pesticide use in forest management in Canada, 1980–1993



Source: National Forestry Database, Canadian Council of Forest Ministers.

Annual trends of fire disturbance, on an ecozone basis, are provided in the appropriate chapters. This discussion presents some general trends. For example, fire suppression within the Pacific Maritime, Montane Cordillera, and Atlantic Maritime ecozones has significantly reduced four- to fivefold, to minimal levels, the area historically affected by fire. Within the Boreal Shield ecozone, fire continues to be a major agent of ecological change; in fact, area burned has increased in recent years. Since the 1950s, harvesting has replaced fire as the major disturbance in the two western ecozones (Environment Canada 1995a). The broad-scale ecological implications of these trends have yet to be determined.

Overall, the area burned declined between 1920 and 1970 but increased in the 1980s to an average of 2.5 million hectares per year (Fig. 11.16). More than 7.5 million hectares burned in 1989, making it the most severe fire year on record. When final statistics are in, 1995 may claim this distinction. Explanations for these recent increases include higher than average temperatures, successive dry winters as well as hot summers, and a change in fire management policy, allowing more remote fires to burn.

During the period 1978–1992, 10 million hectares of commercial timber were burned, compared with a harvest of 13.3 million hectares (Natural Resources Canada 1995a). Large fire losses can seriously affect the steady supply of timber for mills. Harvest plans may have to be altered to salvage timber before rot sets in, creating a short-term oversupply of timber and a potential future undersupply owing to a lack of mature timber.

Influence of harvesting and renewal practices

Harvesting

One percent of the timber-productive forest (0.25% of total forestland) is harvested annually. Almost all of the harvesting in western Canada takes place on previously uncut lands. Second and third rotations of harvest are more prevalent in the Maritimes and portions of the southern boreal, hardwood, and mixedwood forests of southern Ontario and Quebec. Clear-cutting is used for 99% of all harvesting along the B.C. coast, for 90% of harvesting in the country's boreal forest, and for 80–85% of harvesting in the Maritimes and southern Ontario and Quebec (Natural Resources Canada 1994a).

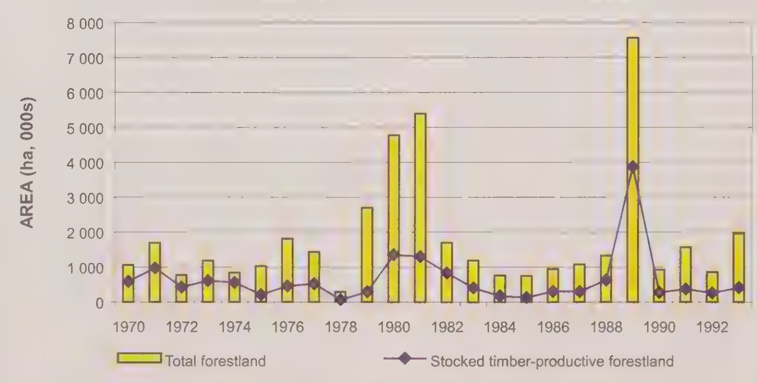
The volume of wood harvested has increased dramatically in recent times. Nine billion cubic metres of wood were harvested from Canada's forests between 1840 and 1990. Half of this volume was cut in the 115 years prior to 1955. The remainder was cut in the succeeding 35 years (128 million cubic metres per year) (Rotherham 1992). Since 1990, the average volume cut has averaged 170 million cubic metres, depending on market conditions (Canadian Council of Forest Ministers 1995a).

The harvested area more than doubled between 1920 and 1993. Levels peaked in the mid-1980s, when 1 million hectares were harvested annually (Fig. 11.17). In some regions, harvesting has increased substantially during the last seven decades. For example, in the Pacific Maritime ecozone, harvesting has almost tripled (from less than 20 000 ha to more than 50 000 ha); in the Montane Cordillera ecozone, a 15-fold increase has occurred (from minimal logging to 150 000 ha) (ESSA Technologies Ltd. 1993).

Differing site conditions and stand characteristics influence the available merchantable volume per hectare. Commercial tree growth within the coastal temperate rain forest of British Columbia is the highest in Canada, having an average mean annual increment (MAI) of 2.3 m^3/ha, compared with 0.8 m^3/ha for the Boreal Cordillera ecozone (Box 11.3). This measure of annual growth reflects the superior growth and older age of the B.C. coastal forest (MacKinnon and Eng 1995). British Columbia harvests the largest volume of roundwood (logs) annually, Quebec the largest area. Table 11.3 provides a provincial and territorial synopsis of annual area harvested versus annual volume of roundwood production.

Nationally, harvest levels are well below allowable annual cuts (AAC) (Fig. 11.18). However, in some regions of Canada, the harvest level is now the same as the AAC level, particularly for softwood species (Natural Resources Canada 1994a). Also, there are several factors that may decrease AACs, including land withdrawals, constraints on harvesting, and scarcity of old growth for some regions of the country.

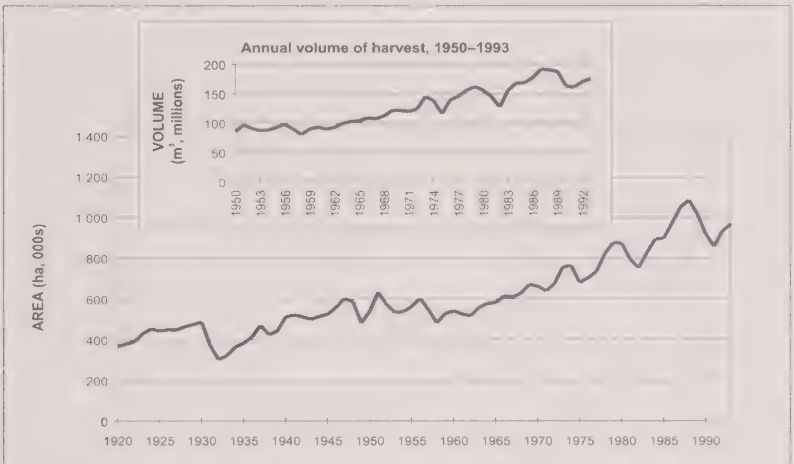
Figure 11.16
Area of forestland disturbed by fire, 1970–1993



Source: National Forestry Database, Canadian Council of Forest Ministers.

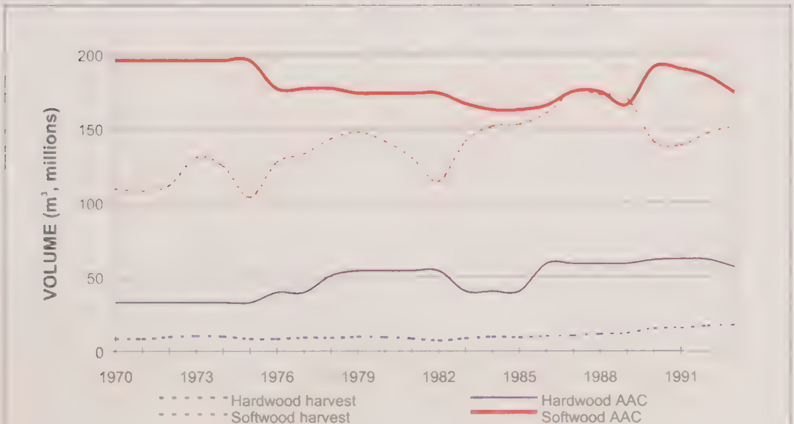
Certain forests within the country are characterized by older-aged trees. Such forests have higher standing volumes per hectare than do younger stands. As the age-class structure of the commercial forest changes with the harvesting of older forests and the implementation of 60- to 100-year rotations, the available volume for harvest will decrease. This change in age-class structure will affect AACs, likely reducing them over time. The implications are not uniform across the nation. In coastal British Columbia, where older commercial forests dominate, AACs for second-growth and subsequent forests may be lower than AACs based on the existing age-class structure. In contrast, the fire-dominated timber-productive forests of boreal Canada are generally younger and more even-aged than the coastal forests. Harvesting may have less impact on future age-class structure and volume in these forests. Regardless, AAC limits, in general, will likely be lowered as governments institute forest policies that reflect input from a broad spectrum of groups and organizations interested in Canada's forests.

Figure 11.17
Annual area and volume of harvest, 1920–1993



Source: National Forestry Database, Canadian Council of Forest Ministers.

Figure 11.18
Allowable annual cut and total annual harvest, 1970–1993



Note: Provincial/territorial governments regulate harvest volumes through the allowable annual cut (AAC), which defines the maximum level of harvest consistent with a sustainable supply of timber.

Source: National Forestry Database, Canadian Council of Forest Ministers.

Regionally, public concern often focuses not on the extent of the area logged, but on where and how that logging is taking place. Many Canadians, for example, see clear-cutting (see Box 11.4) as an ecologically unacceptable practice. Heated conflicts are occurring between industry and environmentalists over the logging of the old growth of the western temperate rain forests (see Chapter 3) and of old Red Pine and Eastern White Pine stands in Ontario (see Chapter 5).

The Clayoquot Sound area of Vancouver Island has been under particular scrutiny by government and environmental organizations. Both the harvest of old growth and clear-cutting are issues. A recent report of an independent scientific panel set up to develop standards for sustainable forest management recommended the replacement of conventional clear-cutting with a "variable retention" logging system (Clayoquot Sound Scientific Panel 1995). In such a system, a variety of ages and sizes of trees and other key ecosystem elements are retained. The panel stated that selective cutting practices, including cable logging, should be considered. The province has accepted most of the recommendations of this panel. In British Columbia, as well as the rest of Canada, clear-cutting will remain under scrutiny.

Other concerns, such as the loss of biodiversity and impacts on wildlife and associated habitat, fuel the clear-cutting controversy. These aspects are discussed in more detail in the regional ecozone chapters (see also Chapter 10 in Government of Canada 1991).

Renewal

The commercial wood supply is depleted by harvesting and by natural factors such as fire, insects, disease, and windthrow. It is increased by human activities such as planting and seeding and by natural factors such as regeneration and the annual growth of the forest. The total wood volume per unit area, as well as the rate of growth in wood volume, can also be increased by silvicultural measures such as thinning or spacing of trees. These factors are integrated into the calculation of AACs.

The total area considered successfully regenerating 10 years after harvest to commercial species increased 10-fold between 1975 and 1992. The area considered not successfully regenerating to commercial species for this same time period peaked at 2.9 million hectares in 1991 and fell to 2.5 million hectares in 1992 and to 2.49 million hectares in 1993 (R. Côté, Canadian Forest Service, Natural Resources Canada, personal communication) (Fig. 11.19). An intensive planting effort in the 1980s concentrated on reforesting the backlog of areas not successfully regenerating and probably accounts for this decrease. Data for 1994 and 1995 are not yet available to allow determination of whether this downward trend is continuing. Between 1979 and 1993, there was a net increase of 3.8% in the volume of trees growing in Canada's commercial forest.

Reasons for unsuccessful regeneration after harvest are several. A small proportion of harvest area is lost as a result of the construction of roads and landings for stockpiling logs and subsequent loading onto trucks. Other areas have not achieved acceptable regenerating levels for reasons ranging from brush competition to altered site conditions after harvesting.

Currently, one-half of harvested areas are successfully regenerating naturally to commercial species. Industry and governments are working together to increase the percentage of successful natural regeneration through improved harvesting and silvicultural methods. Between 1975 and 1993, the area harvested increased by 42%, whereas the area planted or seeded increased by 228% (Fig. 11.20). This increase in regeneration efforts resulted directly from the implementation of Federal–Provincial Forest Resource Development Agreements (which have now finished) with individual provinces. Similar large increases in overall site preparation and stand-tending efforts have taken place.

A successfully regenerating forest in the above context is one that, after harvest or other disturbance, will mature to a well-spaced forest of commercial species at a rate that will meet expectations for future wood supply. Opinions differ on whether such a forest is ecologically desirable. Arguments centre on loss of biodiversity owing to the preference for single-species planting. In some situations, monoculture tree plantations convert formerly diverse forested areas containing a variety of tree species to areas containing a single species. Sometimes more than one species is planted, but original levels of tree species diversity may not be restored (Hammond 1991). Other

Box 11.3
Canada's timber-productive forest land base: key facts

- *Four hundred and eighteen million hectares of forestland exist in Canada (42% of total); 42% of this is timber-productive forest.*
- *Of the timber-productive forest, 45% is young forests, 43% is mature or overmature forests, 5% is uneven-aged or unclassified forests, and 7% is not currently stocked with commercial species.*
- *Of the timber-productive forest, 63% is characterized by softwood, 22% by mixedwood, and 15% by hardwood.*
- *Predominant species by percentage of timber-productive forest:*

all spruces	19%
all pines	15%
Balsam Fir	5%
all hemlocks	2%
Douglas-fir	2%
other conifers	6%
total conifers	***49%***
all poplars	8%
all birches	3%
all maples	2%
other hardwoods	8%
total hardwoods	***21%***
unclassified	***30%***

- *Average rates of growth for timber-productive forestland within the major forested ecozones are:*

Ecozone	*m^3/ha per year*
Pacific Maritime	2.31
Mixedwood Plains	2.07
Boreal Plains	1.82
Montane Cordillera	1.71
Boreal Shield	1.56
Atlantic Maritime	1.55
Boreal Cordillera	0.79
Taiga Plains	0.79
Taiga Shield	0.79

Source: National Forestry Inventory, as compiled in Lowe et al. (1996).

concerns relate to potential loss of genetic diversity, increased risk from infestations of insects and disease, creation of a differently structured forest from the original, and loss of wildlife habitat. Increasingly, scientists are calling for forest ecosystem management that emulates natural forest cycles, which means that current silvicultural prescriptions including regeneration may need to be modified to be ecologically sound (Booth et al. 1993; Kimmins 1993).

The area receiving herbicide treatment to encourage seedling growth has always been small in Canada, never exceeding 235 000 ha annually (see Fig. 11.15). In 1993, more than 90% of the area treated was in British Columbia, Ontario, Quebec, and New Brunswick. Glyphosate was the most widely used product. One application of herbicides per rotation (40–140 years) is usually sufficient (Canadian Pulp and Paper Association 1992).

Mill operations: wastes and recycling

Mill effluent

Because of the impracticality of measuring and regulating all chemicals in pulp mill effluent, regulatory authorities have selected a few indicators, based on ease of measurement and known impacts, for monitoring pollution. These indicators include total suspended solids, biochemical oxygen demand, and dioxins and furans. In 1992, the federal government introduced new nationwide regulations under the *Fisheries Act*, including minimum discharge standards for these parameters and for nontoxic effluents. These Pulp and Paper Effluent Regulations outline minimum standards for all pulp and paper mills.

To meet the federal standards, mills using chlorine bleaching had to modify their processes to prevent dioxin and furan formation. All mills were required to discharge effluents that were nontoxic to fish. Mills that did not already include secondary treatment had to instal such facilities. Mills requiring time to do this were granted Transitional Authorization Extensions, which expired 31 December 1995. At the present time, 157 mills are subject to the requirements of the *Fisheries Act*. Of these mills, one or two are not expected to be in compliance by summer of 1996. Environment Canada has developed an enforcement strategy that includes inspection and investigation plans concentrating on mills that were not in compliance as of January 1996. Routine inspections will continue for all other mills (H. Cook, Environmental Protection Service, Environment Canada, personal communication).

A significant downward trend in total suspended solids and biochemical oxygen demand in mill effluent has occurred over the past several years (Fig. 11.21). Between 1980 and 1993, total suspended solids (kilograms per tonne of pulp produced) dropped by 68%, and biochemical oxygen demand fell by 65%. Between 1988 and 1994, there was a 99.4% reduction in the release of dioxins and furans (Fig. 11.22).

Recycling

One measure of the efficiency with which timber resources are used is the degree to which wood residues and recovered paper are used to produce pulp and paper. Statistics reveal a strong positive trend towards use of wood and paper wastes to produce pulp. In 1965, harvested roundwood accounted for 76% of the raw material consumed by pulp mills. By 1994, this proportion had dropped to 28% (Fig. 11.23). An increase in the roundwood proportion in 1994 was due to increased demand for pulp and paper and lack of an available supply of recovered paper and wood residues (Canadian Pulp and Paper Association 1995).

Table 11.3

Annual area harvested compared with roundwood production, by province/territory, 1990–1993

	Area harvested (ha, 000s)				Roundwood production (m^3, millions)			
Province/territory	1990	1991	1992	1993	1990	1991	1992	1993
Newfoundland	22.1	18.7	18.5	20.6	2.9	2.7	2.8	3.1
Prince Edward Island	2.3	2.1	2.6	3.0	0.5	0.5	0.5	0.5
New Brunswick	80.1	91.6	103.3	100.6	8.8	8.6	9.2	9.0
Nova Scotia	39.3	37.5	33.9	42.8	4.6	4.3	4.2	4.6
Quebec	253.3	236.1	248.5	311.6	30.5	29.6	31.2	30.9
Ontario	238.2	199.5	190.7	206.0	25.4	23.8	24.3	25.4
Manitoba	10.3	8.5	11.4	11.0	1.6	1.3	1.6	1.5
Saskatchewan	16.5	17.2	18.5	19.5	2.8	3.0	3.1	4.4
Alberta	48.4	49.1	55.9	44.6	11.9	12.9	14.6	14.2
British Columbia	218.3	181.5	193.0	221.6	78.3	73.4	79.0	75.4
Northwest Territories	0.3	0.5	0.4	0.5	0.1	0.1	0.1	0.2
Yukon	0.4	0.4	0.6	0.6	0.1	0.1	0.2	0.2
Total	929.5	842.7	877.3	982.4	160.5	161.6	170.8	169.4

Source: Canadian Council of Forest Ministers (1995a) for all data except data for British Columbia (G. Still, B.C. Ministry of Forests, personal communication) and 1993 volume harvested for Quebec (J. Robitaille, Ministère des Ressources naturelles du Québec, personal communication).

The stimulus for Canadian mills to increase the use of waste paper to make pulp has come from the international market, particularly the United States, the largest consumer of Canadian newsprint. By mid-1993, 12 states had passed legislation, and 13 others, plus the District of Columbia, had instituted voluntary programs to increase the use of recycled-content newsprint.

Since 1975, paper and paperboard production in Canada has almost doubled. At the same time, the use of recycled paper in the manufacturing process has increased from 6% to 21%. In 1989, only one Canadian newsprint mill used recycled fibre. By 1993, 22 mills were producing recycled-content newsprint, and 11 mills had installed de-inking and recycling operations. This shift has spurred the introduction of vegetable inks and the development of environmental technologies to treat and dispose of waste and develop alternative uses for it (e.g., fertilizer).

Between 1975 and 1992, the proportion of waste paper diverted from the waste stream for use in paper products increased from 16% to 38%. Few countries that produce pulp and paper have achieved higher recovery rates. Certain countries, such as Japan, have recovery rates as high as 55%. These countries have large populations living in smaller areas, and waste disposal is a major concern, making waste paper collection economically and environmentally responsible. Demand by the Canadian paper industry has driven the recovery of waste paper: Canadian sources cannot meet demand, and much of this raw material is imported from the United States (Natural Resources Canada 1994b).

Another indicator of efficiency of use is the Lumber Recovery Factor, which measures the lumber produced from logs. Lumber recoveries in Canada have increased from 200 board feet/m^3 in the 1970–1980 period to 250 board feet/m^3 in the mid-1990s. Mills incorporating state-of-the-art equipment are expected to produce up to 300 board feet/m^3, which will result in more lumber and less sawdust and chips from each log processed (T. Rotherham, Canadian Pulp and Paper Association, personal communication).

Recycling efforts, however, cannot be expected to reduce harvest levels. Advances in recycling are being outpaced by increases in world demand for wood and paper products. International market conditions affect the volume of roundwood harvested and processed each year in Canada. The demand for Canadian forest products is expected to continue to grow for the foreseeable future.

Forest management and biodiversity

Concern exists regarding whether harvesting and related forest management practices are causing large-scale changes in forest biodiversity in Canada. Biodiversity is a broad and complex topic. Here, the focus is on three components: species composition and structure, old growth, and protected areas. A more detailed discussion of biodiversity can be found in Chapter 14 and the regional ecozone chapters.

Species composition and structure

Box 11.3 contains a synopsis of the major tree species of Canada's timber-productive forests. Trend data on species composition and structure are not available. Under the auspices of the Canadian Council of Forest Ministers, initiatives are in place to develop a national system of indicators to track progress towards sustainable forest management. This system would include indicators of species composition over time (Canadian Council of Forest Ministers 1995b).

Box 11.4
Clear-cutting in Canada

The practice of clear-cutting, the dominant form of logging in Canada, is contentious because of ecological concerns. This form of logging has accounted for 85–90% of the area harvested over the past 20 years. In 1993, clear-cutting was used in 844 000 ha (87%) of total area harvested (Natural Resources Canada 1995a).

A recent report of the House of Commons Standing Committee on Natural Resources concludes that clear-cutting is ecologically appropriate for most forest types in Canada, but additional research is needed on the effects of various harvesting approaches on biodiversity, soil, water, and wildlife habitat. The committee identified "a definite trend toward smaller clear cuts and improved design" (Standing Committee on Natural Resources 1994b).

In 1990, the Canadian Pulp and Paper Association (CPPA) compiled statistics on clearcut sizes by member companies. CPPA reported that the average clearcut size was 60 ha. Clearcuts in Newfoundland had the largest average size (115 ha), with 16% of all clearcuts being greater than 200 ha. Clearcuts in Nova Scotia were the smallest (23 ha), with no clearcuts being greater than 120 ha. Average clearcut sizes within Ontario, Quebec, and British Columbia were 110 ha, 69 ha, and 49 ha, respectively (Canadian Pulp and Paper Association 1992). Eight percent of all Quebec clearcuts were larger than 200 ha. Clearcut size breakdowns were not compiled for other jurisdictions.

Recent provincial legislation and guidelines have moved in the direction of smaller clearcuts. For example, Quebec sets limits of 150 ha for clearcuts within the boreal forest, 100 ha in mixedwood forests, and 50 ha in southern deciduous forests. These limits are less than the previous 250-ha maximum across the province (Anonymous 1994). Similarly, the B.C. government, through the Forest Practices Code of the British Columbia Forest Practices Act *and associated regulations and standards, has recently limited clearcuts to 60 ha in the north and 40 ha in the southern parts of the province.*

However, the trend towards smaller cutblocks is not necessarily good for wildlife or biodiversity. It may increase fragmentation and access-related problems. In some areas, larger cutblocks may be better. The key is to have a diversity of sizes, shapes, patterns, and distributions. Size should be tied to ecological characteristics, including biodiversity of the area being logged.

Areas with road access and commercial operations show some changes in species composition when compared with nonaccessed areas. Generally, forests in accessed areas remain diverse (Natural Resources Canada 1994a), but regional shifts do occur. For example, the coast of British Columbia has experienced an increase in Douglas-fir and a slight reduction in spruce. Forests within the Mixedwood Plains ecozone show a 20% reduction in Eastern White Pine and increases in poplar and Balsam Fir (Brand 1992). The ecological implications of these trends are not known.

In certain parts of Canada, structural changes have been noted. In the Montane Cordillera ecozone, for example, the average age-class of the forest has been increasing as a direct result of fire suppression: areas that formerly were subject to severe burns every hundred years or so no longer have this natural fire cycle. It has also been observed that, because of fire suppression, the forest cover is changing to include more shade-tolerant species (A. MacKinnon, B.C. Ministry of Forests, personal communication).

Because of natural disturbances, Canada's boreal forest was younger in 1920 (averaging 61 years) than it is today (averaging 76 years). A decrease in these disturbances had increased the average age to 83 years by 1970. In the last 20 years, however, the average age has been decreasing again in response to a twofold increase in natural disturbances (Kurz and Apps 1996). These changes may be significant in global climate change because of their implications for carbon storage and release: young regenerating forests may have carbon uptakes that are initially low, whereas natural disturbances lead to increases in decomposing organic matter and consequent release of carbon dioxide. As a result, the Canadian boreal forests, which were essentially carbon sinks from 1920 to 1970, have become sources of carbon to the atmosphere (Kurz and Apps 1995, 1996) (see Chapter 5, Box 5.2).

Old growth

Old-growth forests are dominated by trees that are close to, or older than, their age of maturity. The old-growth stage may be

Figure 11.19
Regeneration after harvest

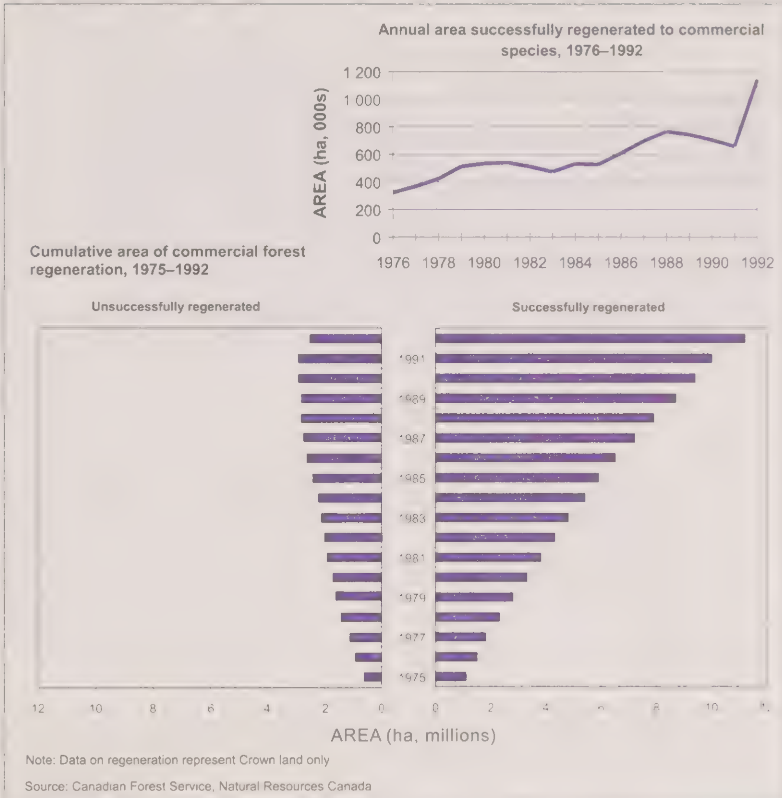
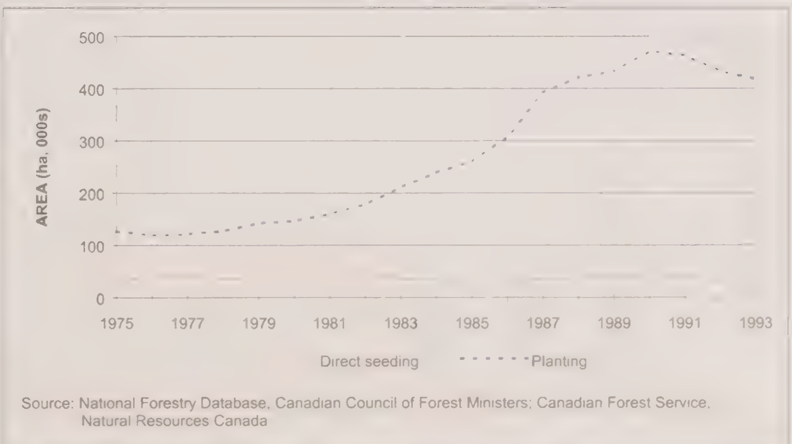


Figure 11.20
Trends in direct seeding and planting of harvested areas, 1975–1993



reached at different ages, depending on tree species and site conditions (Duchesne 1994). Certain old-growth forests have become the focus for major disputes regarding appropriate use. Among the most contentious issues are logging versus conservation of the old-growth temperate rain forests of British Columbia (see Chapter 3), the Eastern White Pine and Red Pine forests of Ontario (see Chapter 5), and the hardwoods of the Maritimes (see Chapter 7).

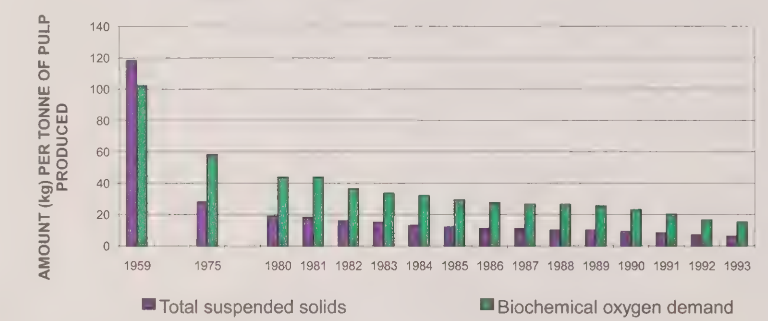
Old-growth forests are a repository of natural diversity that tends to change as they are converted to managed forests with short rotations. Much public interest in their conservation centres on the old-growth forest ecosystems, with their many unrecorded species and general vulnerability to change. There are also many strong spiritual, aesthetic, and recreational values associated with these ecosystems.

The old-growth forests are a source of high-value timber. Over the years, logging has steadily reduced the amount of old-growth forest. In most cases, forest regeneration in these areas is based on a harvest rotation of 80–100 years, eliminating any chance for old-growth conditions to develop again.

Canada has no comprehensive national inventory of its old-growth forests. A rough surrogate, using age-class, may be derived for the timber-productive forestlands, using data available from Canada's National Forest Inventory (Duchesne 1994). However, this inventory, compiled every five years from provincial and territorial data, is not suited for trend analysis (Lowe et al. 1994). Canada's inability to monitor trends in key attributes of forest ecosystems regionally, provincially, or nationally is a major roadblock to determining environmental sustainability and consequently economic sustainability.

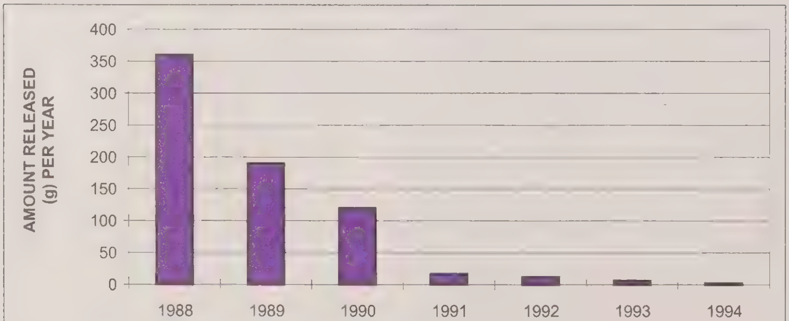
Data from the National Forest Inventory do, however, provide an overview of older forests for the inventoried portions of the country (Table 11.4). Of the timber-productive forest in Canada, 43% is classed as mature or overmature. These two maturity classes are linked to optimal harvest ages for any given species. The age spread for commercially mature trees is generally between 75 and 130 years, whereas overmature trees are usually older than 130 years.

Figure 11.21
Total suspended solids and biochemical oxygen demand of mill effluent, 1959–1993



Source: Canadian Pulp and Paper Association (1995).

Figure 11.22
Dioxins and furans in mill effluent, 1988–1994



Source: Canadian Pulp and Paper Association (1995).

Protected areas

Approximately 22.8 million hectares of forest are protected from logging by legislation in Canada. Within the commercial forest, an additional 27.5 million hectares are unavailable for harvesting for policy, regulatory, and operational reasons. This includes forest occurring on environmentally sensitive sites such as shallow soils, steep slopes, wetlands, or sites adjacent to lakes and rivers. The total area of forest protected from logging either by legislation or by policy represents 12% of Canada's forestlands (Natural Resources Canada 1994a, 1995a).

Whether these protected lands protect biodiversity is unknown. Harvesting and other land use activities have created islands of protected areas that may be too small and fragmented to be sustainable. Large protected areas generally have more ecological value and are better able to maintain biodiversity than small protected areas. The World Conservation Union (IUCN), for example, considers protected areas >1 000 ha as generally ecologically viable (IUCN 1994). British Columbia is the only province to have

published information on protected areas by level of protection, ecological stratification, and size category (B.C. Ministry of Environment, Lands and Parks 1995). Environment Canada is preparing a database — the National Conservation Areas Database — that will allow this tabulation on a national basis.

A goal of Canada's National Forest Strategy is to complete a network of protected areas representative of Canada's forests by the year 2000. However, comprehensive national data are not available to measure progress towards this goal. This deficiency is being addressed in the development of the National Conservation Areas Database. The biodiversity and regional ecozone chapters provide more comprehensive discussions of protected areas within Canada.

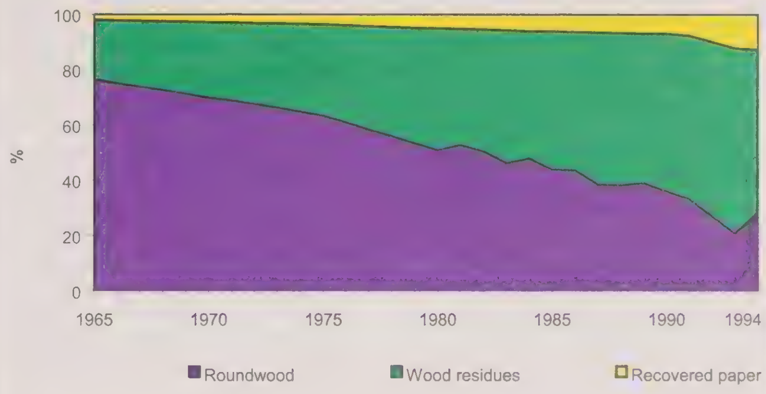
The challenges ahead

Governments are working with industry, environmental groups, local communities, and other nongovernmental organizations to accommodate or reflect different values and uses in policy and management. They are taking steps to define sustainable forest management in concrete terms and to track progress towards it. The driving force behind these initiatives is as much international as it is domestic. Because over 80% of Canada's forest products are exported, international opinion influences forest management policies and practices in Canada.

In 1993, for example, four German publishers announced that they would stop buying pulp and paper products derived from clearcut, old-growth forests as other alternatives became available. In the key newsprint market of the eastern United States, recycling requirements will be increasingly stringent. As of 1996, the required recycled content ranges from 20% to 100%, depending on jurisdiction. These regulations may increase the comparative advantage of American producers, which are located near cities that serve as major sources of the old newspapers and magazines required to make recycled newsprint.

Globally, trade is expanding as historical barriers such as tariffs and quotas are dismantled. However, the tariffs once used to restrict access to world markets may be replaced by environmental measures. Canada is active at both the domestic and international levels in defining and implementing sustainable forest management practices (see section on "International initiatives"). Details of specific provincial initiatives may be found in the appropriate regional chapters.

Figure 11.23
Source of raw materials for pulp and paper production in Canada, 1965–1994



Source: J. Ducharme, Canadian Pulp and Paper Association, personal communication.

Table 11.4
Percentage of timber-productive forest classified as mature or overmature, by province/territory

Province/territory	Total timber-productive forestland (ha, millions)	% mature	% overmature
Newfoundland[a]	11.3	27	25
Prince Edward Island	0.3	–	–
New Brunswick	6.0	37	3
Nova Scotia	3.8	10	<1
Quebec	54.8	48	<1
Ontario	42.2	31	19
Manitoba	15.2	17	3
Saskatchewan	12.6	12	12
Alberta	25.7	31	12
British Columbia	51.7	20	39
Yukon	7.5	27	2
Northwest Territories	14.3	32	<1
Canada	245.4	29	14

[a] Total timber-productive forestland applies to Newfoundland and Labrador, but percentages apply to Newfoundland only.

Source: Compiled from Lowe et al. (1994).

National initiatives

The Canada Forest Accord, signed by governments, industry, and nongovernmental groups in 1992, states that healthy forest ecosystems are essential to the health of

all life on Earth. It commits the signatories to incorporate a wide range of forest uses and interests in forest management. The five-year National Forest Strategy includes a number of steps to improve the national ability to manage forest ecosystems and maintain biological diversity (Canadian Council of Forest Ministers 1992).

The Model Forests Program was established in 1991 to develop new forest management concepts and techniques and to demonstrate ways to integrate environmental, social, and economic values into sustainable forest management practices (Forestry Canada 1992). Ten model forests were established, representing the major forest ecosystems of the country. All cover large areas, with the smallest one being the "Inhabited" Model Forest of east-central Quebec (112 634 ha) and the largest one being the Foothills Model Forest (2.5 million hectares). The sites are managed by partnerships involving industry, environmental and conservation groups, Aboriginal communities, private landowners, educational groups, outdoor recreation clubs, and all levels of government. Research and operational activities are far-ranging and encompass aspects such as wildlife studies, computer analyses, and harvesting methods (Natural Resources Canada 1994a, 1995a).

In October 1995, the Canadian Council of Forest Ministers (1995b) released *Defining sustainable forest management: a Canadian approach to criteria and indicators*. This document identifies 6 criteria and 83 indicators that reflect an approach to forest management based on:

- the need to manage forests as ecosystems to maintain their natural processes;
- the recognition that forests provide a wide range of environmental, economic, and social benefits to Canadians;
- the view that an informed and involved public is important in promoting sustainable forest management; and
- the need for forest management to evolve, reflecting the best available knowledge and information.

These criteria and indicators form the basis of the commitment by the Canadian Council of Forest Ministers to define, measure, and report on the performance of sustainable forest management in Canada.

A Canadian Sustainable Forest Management certification system is being developed by the Canadian Standards Association (CSA) and will conform to future international standards as they are developed. It includes standards covering forest management systems (management plans, permits, and audits) and criteria related to sustainability. This certification program will be available to all companies involved in the forest industry. Certification will be authorized by the CSA after a comprehensive audit by an independent agency (Box 11.5).

The CSA initiative is supported by the forest industry and the federal and provincial forest agencies. Support from environmental organizations, however, is lukewarm. The environmental movement generally favours the approach, philosophy, and criteria developed by the Forest Stewardship Council (FSC) for certification of sustainable forest management (FSC 1994). FSC is an international body that accredits certification organizations in order to guarantee the authenticity of their claims. As with the CSA initiative, participation by the forest industry is voluntary.

Both approaches claim to respond to a consumer need for assurances that forest management and operations are carried out in a sustainable manner. The concern for CSA is the lack of solid environmentalist support, which may result in lack of consumer credibility for the process. For FSC, the concern is lack of industry participation for certification. These concerns, along with the fact that much commonality exists between the two approaches, may lead to an eventual cooperative approach.

The National Aboriginal Forestry Association was created in 1989 to advance the interests and needs of Aboriginal communities, organizations, enterprises, and individuals involved in the forest sector. The organization has proposed an Aboriginal Forest Strategy that is intended to enable Aboriginal people to participate fully in the forest sector. The association calls for new legislation governing forest management on reserve lands; new forest management programs addressing Aboriginal values; and education, training, and business development programs to increase Aboriginal peoples' involvement in forestry (Bombay 1993).

International initiatives

Several key initiatives reflect a global swing to sustainable development:

- *Agenda 21*, a global environmental action plan that aims to encourage the rehabilitation of forestlands and strengthen capabilities to manage forests for a range of values;
- the statement of principles on forests, an agreement arising from the Earth Summit to promote sustainable management of forests;
- the Framework Convention on Climate Change, which addresses the need for countries to maintain forests as sinks or storehouses of carbon; and
- the Framework Convention on Biological Diversity, which commits countries to maintain and protect biodiversity at the genetic, species, and ecosystem levels. Canada has developed a national strategy to implement the convention.

Canada was instrumental in reopening global dialogue on the sustainability of forests, which had been stalled by North–South polarization during discussions associated with the Earth Summit in 1992. Canada cosponsored, with Malaysia, the Intergovernmental Working Group on Forests to address forest-related concerns. This group included developing and industrialized countries, along with intergovernmental and nongovernmental organizations. In 1995, the resulting report guided the United Nations Commission on Sustainable Development (UNCSD) in providing direction to the newly formed Intergovernmental Panel on Forests, whose task was to propose recommendations, by 1997, to the UNCSD on actions needed to address 10 key forest issues defined by the UNCSD.

Canada also initiated the "Montreal Process," an intergovernmental initiative to develop criteria and indicators that define and measure the sustainable management of boreal and temperate forests. Participating countries contain more than 90% of the world's temperate and boreal forests, and membership is growing as the process moves to implementation. Canada has also participated in the "Helsinki Process," which is working to formulate criteria and indicators special to European forests. In doing so, it is promoting consistency between the two initiatives, thereby facilitating comparable reporting.

Canada has expanded its national network of model forests into the global arena. International participation facilitates cooperation to define and apply sustainable forest management within a broad context. At the Earth Summit, Canada pledged $10 million to work with three countries to establish sites. Since then, Mexico, the Russian Federation, and Malaysia have established model forests. The United States joined this network recently, and several other countries have expressed an interest in participating.

Conclusion

Natural disturbances are dominant ecological factors in the life cycle of many of Canada's forests. They affect species composition, age-class structure, and, to a large degree, the carbon cycle of these forests. Forest management can alter these natural cycles through fire suppression and control of insect infestations. The long-term ecological consequences of these natural and human actions combined are not known.

Nationally, the area harvested is minimal compared with the annual extent of natural disturbances. However, on a regional scale, harvesting systems may be major agents of disturbance. Clear-cutting, while controversial, remains the preferred harvest method of industry. Even so, harvesting practices are changing. An example of this is the implementation of the recommendations of the Clayoquot Sound Scientific Panel on harvesting practices within that part of British Columbia. Initiatives and regulations such as the new Forest Practices Code of British Columbia, Quebec's new forest protection strategy, and Ontario's *Crown Forest Sustainability Act* also illustrate the commitment of the provinces to manage forests as ecosystems (see regional chapters for more information on these and other initiatives by the provinces and territories).

The harvest of old growth continues to be an issue of major regional significance. Provincial governments have recognized the need to protect old growth, and several have developed strategies to do this. Still, the logging of old growth remains a major point of contention between industry, governments, and environmental organizations. Differing viewpoints often reflect the jobs versus environment debate.

There is a strong trend away from the use of chemical pesticides to combat forest insect and disease infestations. This trend is expected to continue with increasing use of biological pesticides. With the latter, annual use will fluctuate with infestation cycles. Chemical herbicides, which are used to eradicate competing vegetation so that seedlings can become established, are applied to only a small area annually, and the area of application is not expected to increase.

Arguments continue as to whether maximum harvest limits as reflected by AACs are sustainable. In general, AACs are being lowered. The decline in available old growth, with its associated high volume, is one reason, but there are also additional social and environmental pressures that add up to reduce the available commercial forest land base. The pressures to reduce AACs are expected to continue.

No national ecological inventory and monitoring program exists for Canada's forestlands. This remains a major impediment to the development and monitoring of environmental indicators of forest ecosystem sustainability. Also, there is no consensus on acceptable standards for many indicators of sustainability. For example, conservation of biological diversity is a laudable objective; however, acceptable levels of habitat fragmentation, acceptable changes in species composition, and acceptable population levels remain unclear.

Box 11.5
New standards for sustainable forest management

In early 1994, the entire Canadian forest industry formed a coalition and asked the Canadian Standards Association (CSA) to develop a sustainable forest management certification program. CSA is the preeminent standards-writing body in Canada, having developed standards and certification programs for over 75 years. To develop the program, CSA is working through a technical committee with representation from industry, private woodlot owners, academia, environmental groups, and governments.

The CSA standards will be national in scope while providing for variations in regional conditions. Once the standards are developed, a certification process will be established. It will encompass not only the review of the applicant's sustainable forest management practices, but also on-site inspection of the managed forests. To ensure a credible, consistent, and high-quality certification process, examinations will be conducted by independently accredited auditors. The certification process will include the use of the six broad criteria for sustainable forest management recently endorsed by the Canadian Council of Forest Ministers, local-level indicators, and input from local public advisory groups (Canadian Standards Association 1994).

Publication of the standards is expected in 1996. Field trials using independent auditing firms will be conducted in different regions of the country to test auditing procedures under various forest conditions and management regimes. Analyses of these field trials will lead to further refinement of the standards to enhance the certification process — both its national applicability and its ability to accommodate regional differences in forest conditions and operations.

Great strides have been made in the reduction of pollutants from pulp and paper mills, almost all of which have met the standards related to mill effluent. However, there is still a need to reduce further and eliminate certain toxins. Moreover, uncertainties over the impact of some pollutants remain.

The use of recycled material has tripled since 1980, and more mills are converting to accept such material. In the future, the Canadian supply of recycled materials may not be sufficient to meet demand. Imports of recycled paper have been increasing steadily and now make up over 45% of the total supply. The impact of recycling on harvest volumes is minimal to date and is expected to remain so, as recycling efforts are outpaced by the global demand for paper products.

Forest policies in Canada are shifting from management for sustained timber yield to sustainable forest ecosystem management. The National Forest Accord, the Model Forest Program, the Canadian Council of Forest Ministers' Criteria and Indicators Initiative, the CSA and FSC initiatives to certify sustainable forest management, and provincial initiatives are moving Canada's forest sector towards sustainability. Perhaps the most basic change reflecting this shift is occurring in the decision-making process. Governments, industry, labour, conservation organizations, Aboriginal people, and a wide range of interest groups are trying to address the environmental, economic, and social demands placed on forests. New partnerships are being forged at local, regional, provincial, and national levels. Such partnerships are essential to achieve sustainable forest management.

FISHERIES

Introduction

Canada has a diverse fishery that provides important social and economic benefits to Canada. Although commercial fishing is not a significant factor in the aggregate national economy (less than 1% of the gross national product), it is a major contributor to the economies of the coastal provinces and northern communities. In 1993, primary and secondary production in commercial fisheries and aquaculture contributed $3.2 billion to the economy and provided a surplus of $1.5 billion to Canada's international trade balance. At the same time, commercial fishing, aquaculture, and the fish products industry provided employment for over 150 000 Canadians in all provinces and territories. Although difficult to quantify, it has been estimated that recreational fisheries also contribute significantly to the economy, generating economic activities of $7 billion and supporting over 150 000 full-time jobs (Department of Fisheries and Oceans 1993b). A more detailed description of recreational fisheries appears in the "Outdoor recreation and tourism" component of this chapter.

In recent years, some important fish stocks have been significantly reduced, leading to moratoriums on fishing of many Atlantic groundfish stocks and to a more conservative management regime for Pacific salmon. Declines can be attributed to overfishing, lack of adequate knowledge of the resource and the habitat, interactions among species and their predators, and other ecological factors, such as changing climatic conditions.

For the Atlantic fisheries, the moratoriums have led to severe hardship. Hundreds of communities are economically devastated, and their way of life is threatened. To ensure a future sustainable yield and an enduring source of wealth and jobs, Canada's first priority has been to protect what is left of the stocks and to enable them to rebuild. Despite the highly visible crisis in some stocks, other fisheries (in particular Atlantic shellfish) continue to perform well, maintaining employment and economic benefits in many coastal areas.

This component of Chapter 11 reviews trends in the Canadian fisheries. It presents this delicate resource in its ecological context, addresses the problem of sustainable development, and assesses the progress made so far in this area. It discusses the main environmental issues associated with this sector and, where possible, describes what is being done to reduce adverse environmental and socioeconomic effects.

Socioeconomic changes in Canadian commercial fisheries

Commercial fisheries are a critical source of employment in many coastal and inland areas of Canada. In approximately 1 500 communities, fishing is essentially the sole economic activity. In 1991, there were about 67 000 active fishermen and 75 000 plant workers in Canada (Table 11.5). Canada's commercial freshwater fisheries are mainly concentrated in Ontario, Manitoba, Saskatchewan, Alberta, and the Northwest Territories.

The 1992 moratorium on the cod fishery off Newfoundland affected 12 000 fishermen and an additional 15 000 plant workers. Subsequent closures have increased the job losses to over 40 000. These job losses have occurred throughout Atlantic Canada but have been concentrated in Newfoundland and, to a lesser degree, in Nova Scotia.

Canadian commercial landings fell during the 1990–1993 period (Table 11.6). Quantity dropped by 30%, from 1 644 724 t in 1990 to 1 145 679 t in 1993, yet the landed value fell by only 5%, from $1.48 billion

Table 11.5
Plant workers and fish processing establishments in Canada, 1991

Region	No. of plants	No. of plant workers
Atlantic	900	65 000
Pacific	200	9 400
Inland	200	1 000
Total	1 300	75 400

Source: Department of Fisheries and Oceans (1994f).

to $1.40 billion for the same period. This is explained largely by a 29% increase in landed value of shellfish for the 1990–1993 period. In 1993, the Atlantic coast fisheries accounted for 72% of total landings, Pacific for 24%, and inland for 3%. Compared with the 1989–1992 average of 1 452 486 t and $1.46 billion, landings for 1993 were lower by 25% in volume and by 6% in value (Department of Fisheries and Oceans 1994a).

Canadian fisheries imports increased during the 1990–1993 period (Table 11.7). The value increased by 32% between 1990 and 1993 to more than $1.07 billion (Department of Fisheries and Oceans 1994a). Fisheries exports fell slightly, from $2.66 billion in 1990 to $2.57 billion in 1993, for a reduction of about 3% (Table 11.7). A record export value of $2.77 billion was achieved in 1987 (Department of Fisheries and Oceans 1994a). On average, Canada exports over 80% of its fish production to about 100 countries throughout the world. However, three major markets — the United States, Japan, and the European Community (EC) — together account for approximately 90% of Canada's total fish exports.

In the Arctic, subsistence catches by Aboriginal peoples represent an important part of the Canadian fishery. The replacement value of the subsistence Arctic fishery has been estimated at $15 million, with an additional $7 million in economic benefits to Canada. Although no national data are available on the size of the Aboriginal catch, this fishery is particularly important in British Columbia, where there are approximately 90 000 status Indians and 192 bands on 1 600 reserves. In British Columbia, the Aboriginal (First Nations) catch is about 1 million salmon annually (approximately 3% of the region's total salmon landing) (Department of Fisheries and Oceans 1994b).

Trends in selected Canadian fisheries

The Canadian commercial fisheries fall into two categories: marine, which account for 95% of the total production value, and freshwater, which account for the remainder. The marine fisheries are concentrated on the Atlantic and Pacific coasts. In the Arctic, commercial fisheries are limited and essentially exploratory. However, fisheries provide one of the few sources of employment in more than 50% of the Arctic Aboriginal communities.

Northwest Atlantic fisheries

In recent years, northwest Atlantic groundfish stocks have shown an overall decline in abundance and catch, owing mainly to fishing pressure and environmental variations. In contrast, several pelagic and invertebrate species have remained stable or shown significant increases over the same period, in some cases to well above the long-term average levels (Department of Fisheries and Oceans 1994c).

Subsequent to the establishment of the 200-nautical-mile zone in 1977, groundfish catches by Canadian fishermen nearly doubled, reaching 800 000 t in 1982. Increases in fishing capacity and in capital investment were mostly responsible for this sharp increase. In 1992, catches were about half of the peak values (Fig. 11.24). In 1993 and 1994, the decline continued, with catches reaching the lowest levels in recent decades. The lack of cod, which normally made up half of the groundfish catch, has been the major contributor to the overall decline. In 1992, a two-year

Table 11.6
Profile of Canadian commercial fisheries, 1989–1993

		1989		1990		1991		1992		1993	
Species	Regions	Q (t)	V ($, 000s)	Q (t)	V ($, 000s)	Q (t)	V ($, 000s)	Q (t)	V ($, 000s)	Q (t)	V ($, 000s)
Groundfish	Atlantic coast	684 504	359 161	646 161	386 456	623 221	395 896	464 157	315 553	286 634	187 221
	Pacific coast	132 084	72 946	139 538	85 550	161 538	100 925	162 280	98 275	126 568	88 988
	Canada	816 588	432 107	785 699	472 006	784 759	496 781	626 437	413 828	413 202	276 209
Pelagic and other finfish	Atlantic coast	359 939	85 414	423 407	84 495	304 540	69 493	286 637	69 844	281 031	74 157
	Pacific coast	130 074	326 850	142 263	340 074	125 886	250 265	102 370	246 587	126 627	259 078
	Canada	489 467	412 264	565 670	424 569	430 426	319 758	389 007	316 431	407 658	333 235
Shellfish	Atlantic coast	227 816	503 531	227 116	460 412	225 258	533 004	238 214	587 163	260 030	634 595
	Pacific coast	21 237	45 157	21 521	46 051	24 538	46 835	31 201	62 350	26 789	73 485
	Canada	249 053	548 688	248 637	506 427	249 796	579 839	269 415	649 513	286 819	708 080
Total sea fisheries	Atlantic coast	1 217 713	959 775	1 296 684	936 020	1 153 019	1 007 781	989 008	984 139	827 695	902 244
	Pacific coast	283 395	453 664	303 322	479 943	311 962	406 888	295 851	416 127	279 984	422 611
	Canada	1 555 108	1 413 439	1 600 006	1 415 963	1 464 981	1 414 669	1 284 859	1 400 266	1 107 679	1 324 855
Inland fisheries	Canada	51 199	82 690	44 718	66 413	77 184	73 402	38 697	70 354	38 000	76 200
Grand total	Canada	1 606 307	1 496 129	1 644 724	1 482 376	1 542 165	1 488 071	1 323 556	1 470 620	1 145 679	1 401 055

Q = quantity; V = live-weight value.

Note: 1993 data are preliminary estimates.

Source: Department of Fisheries and Oceans (1994a, 1995e).

Table 11.7
Value of total Canadian fisheries imports and exports, 1990–1993

Region	Value ($, millions)							
	1990		1991		1992		1993	
	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
Atlantic	174	1 708	240	1 631	220	1 647	288	1 652
Pacific	226	775	197	702	246	723	344	805
Inland	330	175	345	127	373	121	438	116
Canada	730	2 658	782	2 460	839	2 491	1 070	2 573

Source: Department of Fisheries and Oceans.

moratorium on fishing the Northern Cod stocks was imposed by the federal Department of Fisheries and Oceans. Since then, the department has extended the moratorium for an undetermined period and has closed fishing for other cod and groundfish stocks in the Atlantic region (Department of Fisheries and Oceans 1994c).

Catches of pelagic fish peaked at 506 000 t in 1968, declined to 198 000 t in 1982, and reached a second peak of about 400 000 t in 1988. Since then, catches have been declining (Fig. 11.24). Herring stocks were the most important Canadian pelagic fisheries in the northwest Atlantic region. Catches have been relatively stable in recent years, with landings in the order of 250 000 t annually. Capelin, on the other hand, exhibited a marked decline in the 1990s. Harsh environmental conditions may have affected their abundance, their migration, and their availability in offshore areas. Although other pelagic species such as mackerel remain abundant, Bluefin Tuna is currently at a low level (Department of Fisheries and Oceans 1994c).

Landings of all invertebrate (shellfish) fisheries increased steadily from the early 1970s to 1991, probably because of favourable environmental conditions and an increased demand for seafood (Fig. 11.24). In recent years, the combined landed value of lobster, Snow Crab, Northern Shrimp, and scallops has accounted for well over half the landed value of all Atlantic coast fisheries. Both lobster and shrimp landings increased significantly and steadily over the 10 years up to 1991; lobster landings have since declined somewhat, but shrimp landings have continued to increase. Snow Crab landings increased from the early 1970s to the mid-1980s, underwent a sharp decline in the late 1980s, and have since recovered (Department of Fisheries and Oceans 1994c).

Anadromous fish species of importance in this region include the Atlantic Salmon, the Arctic Charr in Labrador, and the Gaspereau (Alewife) in the Maritime provinces. Catches of Atlantic Salmon declined from a high of 2 863 t in 1967 to 470 t in 1992 (Fig. 11.24). The 1992 catch was distributed between recreational (42%), Aboriginal (7%), and commercial (51%) fisheries. Quotas were imposed in 1990 and 1991, and a five-year moratorium on commercial fishing was introduced to insular Newfoundland in 1992 in response to steep stock declines (Department of Fisheries and Oceans 1994c).

Northeast Pacific fisheries
In the Pacific region of Canada, five main species of salmon support major fisheries: Chum, Pink, Sockeye, Chinook, and Coho. Based on the average for the years 1989–1992, approximately 94% of salmon were caught by the commercial fishery. The remaining 6% were equally divided between the Aboriginal food fisheries and the recreational fisheries. Total catches of salmon in B.C. waters were above the long-term average in the early 1990s (Fig. 11.25). During the period 1982–1992, catches averaged about 82 000 t, with a peak catch of approximately 108 000 t in 1985.

Salmon production depends heavily on environmental conditions in the North Pacific. Recently, links between Pacific salmon production in the North Pacific (Canada, Japan, the Russian Federation, and the United States) and specific marine climatic factors have been determined: it now appears that conditions were particularly favourable for salmon production in the early 1990s (Department of Fisheries and Oceans 1994c).

Since 1981, there has been a dramatic increase in Canadian landings of groundfish on the Pacific coast (Fig. 11.25). This increase is primarily the result of more landings of hake and, to a lesser degree, rockfish. Pacific Hake dominates the Canadian landings of groundfish on the Pacific coast (Department of Fisheries and Oceans 1994c).

The Pacific invertebrate fisheries have rapidly developed in recent years owing to the strong demand for a number of species (Fig. 11.25). The Geoduck is the species representing the highest landed value, accounting for 34% of the total landed value of invertebrates in 1993, followed by crab at 23%, prawns at 13%, and sea urchins at 11% (Department of Fisheries and Oceans 1995a).

Freshwater fisheries
Canada has about 9% of the world's renewable supply of fresh water. The species of greatest economic importance for commercial fishing include trout, Walleye, Yellow Perch, Rainbow Smelt, whitefish, Northern Pike, and various bass species. Catches of these species have remained relatively unchanged since 1990.

The annual commercial catch of freshwater fish in Canada averaged 50 800 t from

1955 to 1982 and totalled 44 718 t in 1990, representing a landed value of $66.4 million. In 1993, the total catch was lower (38 000 t), but the landed value was higher ($76.2 million) (see Table 11.6).

Ontario, Manitoba, Saskatchewan, Alberta, and the Northwest Territories contribute about 95% of the Canadian commercial freshwater fishery catch. Table 11.8 shows the landings and values for these areas from 1987 to 1992. In Ontario, the catch, which was mainly from the Great Lakes, declined somewhat every year throughout this period. Pollution, overexploitation, and the introduction of exotic species are among the factors influencing the declines of some Great Lakes species (Government of Canada 1991). To counter the declines, efforts are continuing to reintroduce species such as Atlantic Salmon and Lake Trout. The other provinces and the territories show fluctuations in landings and values over the six-year period (Table 11.8).

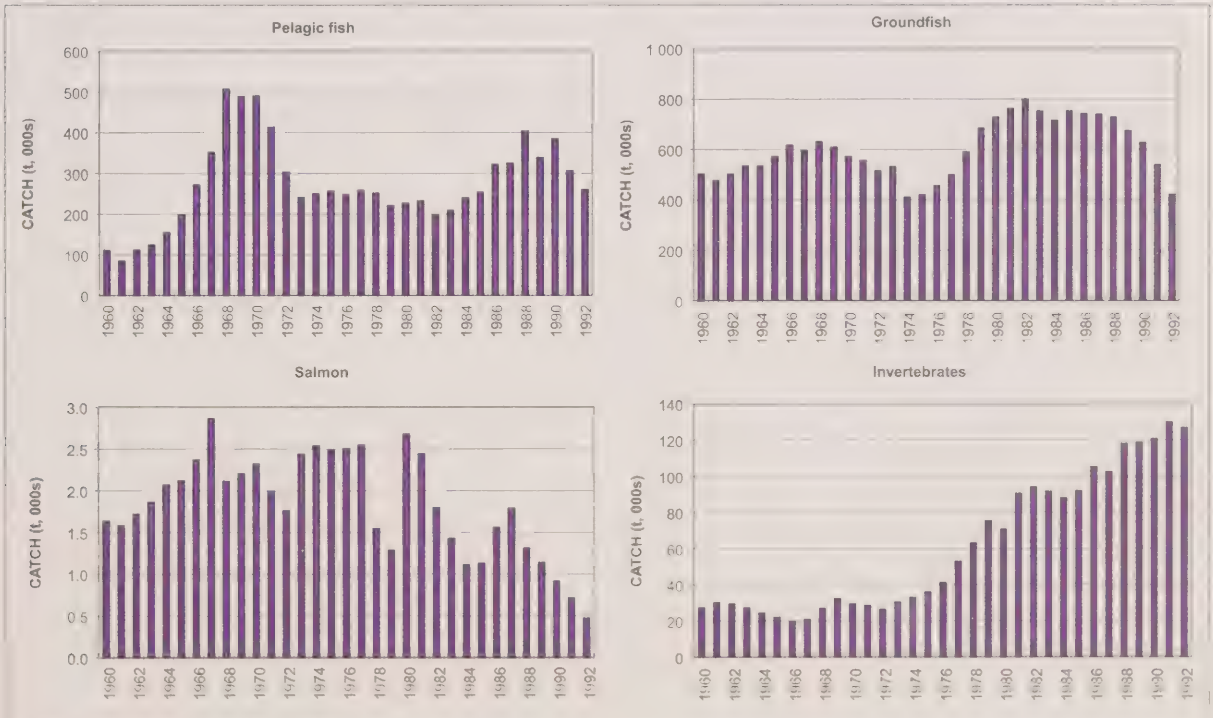
Fisheries issues

Fisheries in Canada suffered acute and highly visible crises in the early 1990s, following drastic reductions in abundance of key stocks (Atlantic groundfish, Pacific salmon). Severe reductions in allowable catches, including closure of many fisheries for groundfish, have been imposed as a first step in rebuilding stocks. In recent years, economic and environmental pressures have significantly reduced some of Canada's best stocks. Factors directly or indirectly contributing to the decline of many stocks include overharvesting, inappropriate fishing practices, changes in environmental conditions (such as variable climatic conditions and natural cycles in productivity and food web structure), the lack of knowledge about the resource and the habitat, and interactions among species and their predators (Box 11.6).

Stock depletion

Conservation of Canadian fish stocks requires a balance between harvesting levels and the biological productivity of the fish stocks. Despite what was generally considered to be a stringent conservation regime, several fish stocks in Atlantic Canada, most notably the cod, have suffered precipitous declines in recent years. The 10 principal cod and flatfish stocks declined from 500 000 t in 1988 to an estimated 50 000 t in 1994 (Department of Fisheries and Oceans 1993a). It is evident that harvesting levels for these stocks must have exceeded their production levels. This imbalance appears to have resulted from an underestimation of

Figure 11.24
Trends in selected Canadian fisheries: northwest Atlantic catches, 1960–1992



Source: Department of Fisheries and Oceans (1994c).

Figure 11.25
Trends in selected Canadian fisheries: northeast Pacific catches, 1960–1992

Source: Department of Fisheries and Oceans (1994c).

harvesting levels and an overestimation of production levels.

Harvesting levels are based on catch reports, which are required from harvesters as part of fisheries management plans. The reliability of catch reports has declined as a result of increased discarding at sea and catch misreporting. On a national basis, discarding at sea and catch misreporting resulted from fierce competitiveness within an industry plagued by excess capacity, both in labour and in capital. On an international basis, fish stocks migrating beyond the 200-nautical-mile exclusive fishery zone were the object of non- or misreported harvesting by foreign vessels fishing in defiance of the Northwest Atlantic Fisheries Organization (NAFO) regulations[1] (see Fig. 11.26 below). As a result, reported catches underestimated harvesting rates of the fish stocks.

Production levels have been estimated through the use of biological models. Available models focus on single species and determine the best harvest level by considering how its population is affected by fishing. It is now recognized that such models are not adequate to estimate sustainable harvest levels of fish stocks subject to environmental changes. The interactions of fish with other species (e.g., predator–prey relationships) and the marine ecosystem are constantly changing. Disregarding the impact of these changes on the production dynamics of fish stocks can lead to erroneous estimations of their productivity, as may have happened in the case of the Northern Cod stocks. These factors are not well understood and are difficult to measure and to model. Intensive research is now under way to better understand and predict stock productivity in a variable environment.

One way in which Canada is attempting to conserve fishery resources is through reducing fishing capacity and the workforce in the provinces affected by the Atlantic groundfish crisis. This effort will result in a fishery that is better adjusted to the production capacity of the marine ecosystem. In turn, this should greatly reduce the temptation to misreport catches (see Box 11.7).

To further strengthen the conservation regime in waters outside the 200-nautical-mile exclusive fishery zone, Canada passed a law in 1994 giving it the authority to protect fish stocks migrating outside this fishery zone. This measure, along with the compliance of foreign and domestic vessels to NAFO regulations, should ensure that

1. NAFO, which is responsible for managing stocks beyond the 200-nautical-mile zone, has 15 member states, including Canada.

Table 11.8

Landings and value trends of major inland commercial fisheries, 1987–1992

Province/territory	1987		1988		1989		1990		1991		1992	
	Landings (t)	Value ($, 000s)	Landings (t)	Value ($, 000s)	Landings (t)	Value ($, 000s)	Landings (t)	Value ($, 000s)	Landings (t)	Value ($, 000s)	Landings (t)	Value ($, 000s)
Ontario	27 759	48 340	27 591	54 710	25 610	48 123	24 853	42 370	23 134	38 140	19 639	41 523
Manitoba	12 151	25 313	14 094	25 196	14 699	21 538	12 273	15 650	12 693	19 973	13 624	24 960
Saskatchewan	3 860	5 153	3 680	4 672	3 904	4 165	2 964	2 704	3 890	3 527	3 797	4 223
Alberta	1 866	2 263	2 185	2 842	1 594	1 912	1 525	1 395	1 773	1 537	1 875	1 951
Northwest Territories	1 572	2 628	1 747	2 763	1 954	2 730	1 769	2 052	1 860	1 854	1 538	1 537
Total	47 208	83 697	49 297	90 183	47 761	78 468	43 384	64 171	43 350	65 031	40 473	74 194

Note: Landings are in live equivalent tonnes.

Source: Department of Fisheries and Oceans (1994d).

managing agencies are provided with realistic harvesting rates.

Foreign fishing

Very few of the fisheries within Canada's 200-nautical-mile zone are exploited by foreign (registered outside Canada) vessels. Foreign vessels are given limited access to harvest species not traditionally fished by Canadians (e.g., Silver Hake). The exclusive fishery zone does not cover all of the continental shelf off Atlantic Canada; some 10% of the Grand Banks (the Nose and Tail) off Newfoundland are outside the 200-nautical-mile zone, as is the Flemish Cap (Fig. 11.26). Stocks that occur outside the 200-nautical-mile zone are classified as "straddling" (stocks that are present on both sides of the 200-nautical-mile boundary of the fishing zone) or "high seas" (those stocks completely outside the 200-nautical-mile zone). Conservation of stocks outside the zone is under the auspices of NAFO.

A sustainable Canadian fishery depends upon international cooperation. Foreign vessels have fished in the northwest Atlantic for centuries. Given uncertainty about their catches and their impact on fish populations, these activities remain a threat to a sustainable fishery. Some unregulated fishing continued outside the 200-nautical-mile zone after its declaration in 1977. Between 1985 and 1992, the EC set catch quotas for their vessels that were above NAFO recommendations, and underreporting of catch by EC vessels was suspected. In 1992, the EC agreed to comply with NAFO decisions and to cooperate with Canada in monitoring catches.

In 1994, at the same time that Canada was closing fisheries on a number of groundfish stocks, NAFO agreed to a moratorium on 6 of the 10 stocks it dealt with in that year. Also, as stated above, the federal government enacted legislation giving Canada authority to arrest stateless and flag-of-convenience vessels fishing straddling stocks adjacent to the Canadian zone. By late 1994, very few foreign vessels were fishing on the Nose and Tail of the Grand Banks. Canada is continuing diplomatic efforts to end fishing by vessels of flag-of-convenience states and states that are not members of NAFO. A dispute with the EC regarding fishing for turbot (Greenland Halibut) on the Nose and Tail was resolved in 1995 with the strengthening of the catch inspection and reporting system under NAFO.

A number of international and bilateral maritime boundary decisions and transboundary fisheries management agreements have been established, such as the Gulf of Maine Boundary Adjudication, the Canada–United States Fisheries Agreement (1990), the North Pacific Anadromous Stocks Convention, the North Pacific Marine Science Organization Convention (1991), and the Canada–France Boundary Adjudication (1994). In addition to these international and bilateral arrangements and negotiations, Canada participates in a number of international fisheries commissions and organizations (including NAFO, in which it plays a lead role), as well as other international forums.

In addition to working with NAFO and bilaterally, Canada participates in other international initiatives aimed at regulating high-seas fisheries. These include a United Nations conference on straddling and highly migratory fish stocks that has developed management measures to complement the United Nations Law of the Sea, whereby states manage their 200-nautical-mile fishing zones; and adoption by the United Nations Food and Agriculture Organization of an international compliance agreement that requires member countries to control high-seas fishing by vessels flying their flags and to respect internationally agreed conservation agreements. This agreement will come into force upon acceptance by 25 states.

Habitat degradation

The loss or degradation of fish habitat is a crucial issue in the conservation of fish stocks. Habitat degradation through pollution or through harmful physical disruption has a direct influence on fish production and on human use of fish. Pollutants enter fish-bearing waters from a variety of point and non-point sources, such as municipal sewage, acid rain, industrial effluent, stormwater, agricultural runoff, and pesticides. Loss of habitat stems from various factors, including urbanization, forest clear-cutting, hydroelectric development, and coastal zone

development (Hargrave 1994). For a detailed discussion of the impact of coastal zone development and pollutant/contaminant issues, refer to the "Oceans" component of Chapter 10.

Shellfish fisheries are closed when the bacteriological quality of the water declines to a point at which it could adversely affect the health of people consuming shellfish from that water. These closures provide a general indication of the extent of sewage, urban stormwater, septic tank seepage, and agricultural runoff entering the coastal zone. Across Canada, the area of closures has increased markedly since 1988 (see Chapter 10, Fig. 10.23). The reduced water quality does not inhibit shellfish production.

The impact of the fishing industry on benthic habitat has been raised as a concern. Fishermen using trawls, rakes, and dredges (also known as mobile fishing gear) to

Box 11.6
What have we learned?

Human capabilities in assessing, monitoring, and conserving fish stocks have lagged behind human abilities to harvest fish. Some fish stocks in the northwest Atlantic and on the Pacific coast have been exploited beyond sustainable levels. Industry and government recognize that fishing capacity must be reduced and fishing patterns changed to ensure sustainable fisheries in the future.

Quantifying the abundance and growth of target species and understanding their dynamics within the complex marine ecosystems of which they are part are difficult scientific challenges, and knowledge has not been adequate to ensure sustainability in some heavily exploited fisheries. Lessons learned from the collapse of fish stocks must be applied to managing healthy resources to ensure they avoid a similar fate and to bringing collapsed stocks back to productive levels. Some recurring themes have emerged from discussions involving fishermen, plant owners, resource managers, fisheries scientists, environmental groups, and communities as they work towards sustainable fisheries in the future. These include the following:

1. ***Conservation is paramount** — The Minister of Fisheries and Oceans has publicly stated that the protection of fish is the first priority, given the critical importance of the fisheries to the survival of hundreds of coastal communities in Canada.*
2. ***Precautionary approach as a guiding principle** — Where there is uncertainty or lack of knowledge, domestic and international fisheries for existing or new species should be managed with caution. Factors influencing abundance estimates are difficult to quantify, and, rather than relying on the most optimistic forecasts, as was sometimes done in the past, lower estimates in the range should be accepted until predictive abilities are improved.*
3. ***Cooperation is essential** — Fishermen and fisheries scientists must actively cooperate in gathering high-quality data that can lead to improved assessments of fish stocks. Fishermen, communities, and government managers must work together to ensure resource conservation and fishery sustainability.*
4. ***There must be an ecosystem and multispecies focus** — The relationship between consumers, producers, predators, and competitors in the marine ecosystem must be better understood and this knowledge applied to managing fisheries. Single-species approaches have their weaknesses, and these have contributed to stock management problems in the past. Such approaches must be used with caution and with an understanding of how other parts of the system affect the species under consideration. The transition to a truly multispecies approach is a challenging but necessary undertaking.*
5. ***Marine protected areas may be considered to ensure protection of spawning and nursery areas and biodiversity** — Collective efforts to conserve and better manage fisheries in the future may still fail owing to unforeseen circumstances and lack of knowledge. Marine protected areas or refuges are receiving increasing interest as a safeguard against failures of other parts of the management system.*
6. ***Ocean climate is important, as it affects the growth rates, distribution, physical condition, and survival of fish** — Water temperature, salinity, ice cover, and other factors acting at local, regional, and global scales must be monitored and accounted for in evaluating stock status and incorporated into fisheries management. Knowledge of the influences of the physical environment on marine resources is constantly increasing and must be applied to fish stock management.*
7. ***Environmentally friendly fishing gear and practices must be adopted** — Undesirable practices contributed to the decline of many fish stocks. Occurrences of by-catch, discarding, misreporting, and high-grading for larger fish have at times been frequent and widespread. Some types of fishing gear do not accurately select for a given target species, and some are widely believed to disrupt fish habitat. The development and adoption of selective gear, codes of conduct for responsible fishing, conservation harvesting plans, and closed areas are means identified to address these problems.*
8. ***There must be binding agreements on international and straddling fisheries** — Many species of fish and marine mammals are highly migratory and fished by many nations; others straddle the fishing zones of coastal states and the high seas. These stocks require concerted and cooperative management efforts by the international community. Many international fisheries agreements and conservation initiatives lack binding protocols for enforcement and dispute resolution. Canada has worked to strengthen international law as it relates to conservation of marine resources. Agreements on international and straddling fisheries must be binding.*

catch bottom-dwelling finfish and shellfish may affect benthic habitat and benthic production processes (Brylinsky et al. 1994) (see Box 11.8 for a discussion of fishing techniques). In 1994, the Fisheries Resource Conservation Council established a subcommittee to study the conservation issues surrounding fishing gear. Meanwhile, the federal Department of Fisheries and Oceans is conducting research on the Grand Banks to determine the level and duration of the effects of otter trawls on benthic habitat.

The Policy for the Management of Fish Habitat guides the Department of Fisheries and Oceans in managing habitat. The policy's principle of "no net loss" is applied on a project-by-project basis to ensure that potential adverse effects on habitat from project development are either avoided or mitigated. Where impacts cannot be mitigated, project proponents are required to replace habitat or fish stock. Provinces that manage their freshwater fisheries also manage fish habitats under their own environmental laws and permitting processes. Where significant fish habitat concerns exist, projects are referred to the federal Department of Fisheries and Oceans for review. The department is also developing fish habitat protection, restoration, and development guidelines in cooperation with several provinces and is involved in other activities that promote fish habitat stewardship (see Chapter 10 for more details).

Aquaculture

Commercial aquaculture in Canada began in the 1950s and remained in a developmental stage until the early 1980s. Production centred on trout culture in Ontario and British Columbia and oyster culture in British Columbia, Prince Edward Island, and New Brunswick.

The first wave of aquaculture development took place between 1984 and 1991. During this period, the production value for the four main species increased more than 36-fold, from $7 million to more than $250 million, recording an extraordinary average growth of 67% per year (Department of Fisheries and Oceans 1995b). The industry expanded to every province and the Yukon, whereas the species base broadened to include salmon, mussels, clams, scallops, Arctic Charr, and marine plants. In 1991, the commercial aquaculture industry provided more than 5 200 jobs, about 2 800 in the production sector and 2 400 in the supply and services sector (Department of Fisheries and Oceans 1993b). About 80% of aquaculture production is exported (Department of Fisheries and Oceans 1993b).

In 1993, Canadian aquaculture producers generated more than $289 million. Salmon, trout, oyster, and mussel are the principal farm-raised species, with a production value of more than $284 million in 1993 (Table 11.9). In 1993, the output from these species was 49 493 t, or 4.3% of the total Canadian fisheries production. However, aquaculture accounted for more than 17% of the total fisheries landed value (Department of Fisheries and Oceans 1995b). Additionally, the supply and services sector of the aquaculture industry generated more than $266 million annually, including more than $53 million in exports.

Although there have been significant socioeconomic benefits from the expansion of the aquaculture industry in Canada, especially in coastal regions, there is concern regarding the potential impact of this development on the coastal ecosystem. These concerns centre on visual impacts, fouling of the benthic environment under pens and the water around them, interference with recreational/commercial fishing and boating, introduction/transportation of fish disease and its impacts on native wild stocks, reduction in genetic diversity due to wild and cultured stock interbreeding, and competition between native wild stock and escaped cultured fish for habitat and food resources.

Many of these concerns have been addressed. For example, in British Columbia, the impacts of waste feed and fecal material on the benthos are primarily local and can largely be avoided by proper siting

Box 11.7
Nova Scotia and the groundfish stocks

The collapse of the Atlantic groundfish stocks had a substantial impact in Nova Scotia. Between 1992 and 1993, groundfish landings and landed value declined by 33% as a result of closures or quota reductions. The number of licensed fishermen declined from 10 300 in 1989 to 8 100 in 1993, and fish plant workers from 7 300 to 5 600 (Statistics Canada 1994b).

The various sectors in the industry acknowledge that a significant reduction in fishing is necessary to rebuild the groundfish stocks. In response, the province has placed a moratorium on the licensing of new fish plants for traditional species (fish plant licensing is a provincial responsibility, whereas resource conservation and management are federal responsibilities). The province has also acted in an advisory role at international meetings and conferences that have addressed the management of straddling stocks and large pelagic fish — for example, the International Commission for the Conservation of Atlantic Tuna.

The Nova Scotia fishing industry has been more diversified than that in, for example, Newfoundland, and it has exploited a variety of species rather than depending heavily on groundfish. Thus, although groundfish catches are down, the industry is still receiving good yields from some traditional invertebrate stocks (particularly lobster). In addition, the industry has moved to harvest nontraditional species (skate, sea urchin, Rock Crab, Silver Hake, dogfish and other sharks). The total fish landings dropped by 19% from 1992 to 1993, but the landed value declined by only 8%, and for these years seafood products led all other provincial exports, for a total annual value of some $750 million (Marketing Division, Nova Scotia Department of Fisheries).

of the culture operation (Department of Fisheries and Oceans 1993c). In addition, there is no evidence that wild fish in British Columbia are at serious risk from disease in farmed fish, and it appears that the potential for reducing genetic diversity of wild stock through breeding with cultured fish is low (Department of Fisheries and Oceans 1993c). Similar concerns have been noted for the Atlantic coast and are addressed through application of regulations, policies, and guidelines.

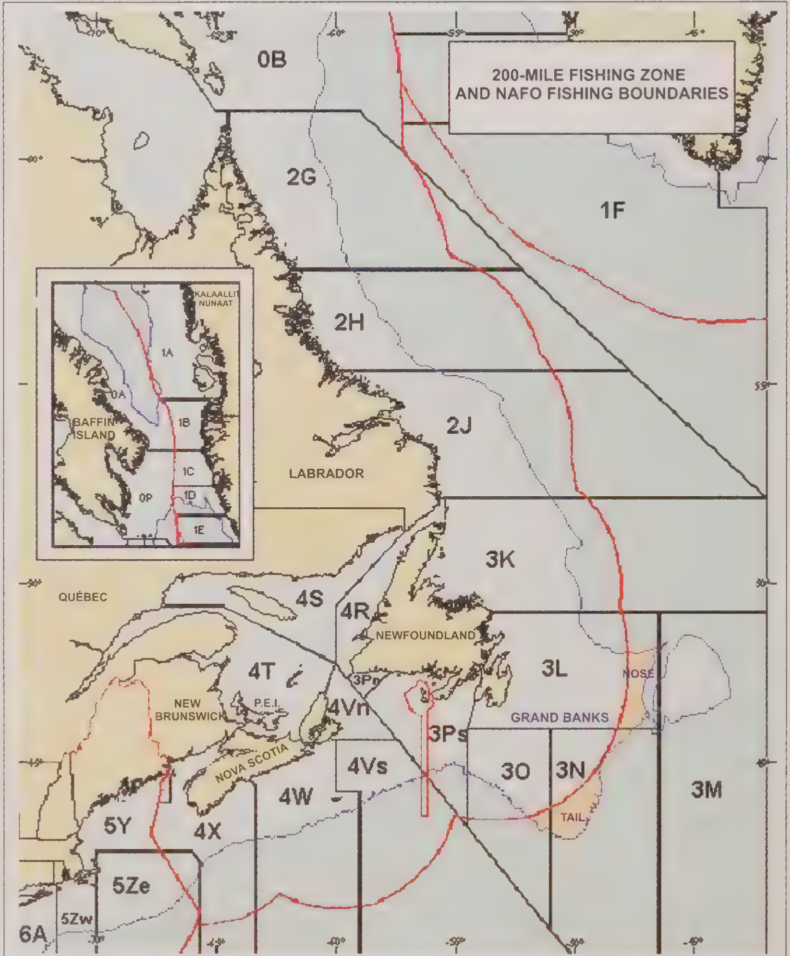
On the Atlantic coast, the impacts of deposition are a greater concern because of the shallower locations in which marine cages are sited. In New Brunswick in 1992, a study of the seafloor around 48 cage sites in about 12 m of water indicated that 8 sites had high impact on the bottom, 29 had moderate impact, and the remaining 11 had low impact (Thonney and Garnier 1992). The industry has responded to many of these concerns by developing diets designed to enhance survival and growth and reduce disease. These measures are linked with feeding regimes such as demand feeding that reduce waste and deposition (Stewart 1994). Furthermore, the Province of New Brunswick, through its Water Quality Regulation permit process, stipulates general and specific environmental requirements that must be met by each inland aquaculture site. All stakeholders in aquaculture recognize the importance of harmony between the industry and the environment if a sustainable fishery is to be realized.

Sustainable fisheries for Canada: initiatives and strategies

The goal of fisheries resource management in Canada is to ensure a sustained flow of economic and social benefits while ensuring biological conservation. Biologists assess the status of fish stocks and the impact of harvesting levels when information permits; harvests are managed for given economic and social benefits. However, it is difficult to manage the fisheries, especially those for which the stock is declining and for which there is pressure to maintain traditional economic benefits. Solutions have not been easy to find. Active participation by industry stakeholders in resource conservation and the involvement and support of federal and provincial governments are required.

The federal Department of Fisheries and Oceans and the provinces are working together on a number of fronts to ensure sustainable fisheries for Canada. A long-term strategy has been developed to allow the fishery in Atlantic Canada to recover from its current crisis. Some of the initiatives include reducing the capacity of the industry (vessels and processing plants), retraining harvesters and processors to allow them to take up employment outside the fisheries, and exploring new and more responsible fishing practices, including research on fishing gear technology. Late in 1992, an independent, broadly based Fisheries Resource Conservation Council was established to make recommendations to government for conservation of Canada's Atlantic fish stocks.

Figure 11.26
Northwest Atlantic fishing zones



Source: Department of Fisheries and Oceans.

On the Pacific coast, a federal–provincial panel reviewed the problems associated with management of the Fraser River Sockeye Salmon resource in 1994. The study has led to stringent new conservation measures. Negotiations are ongoing with the United States to find a solution to conflicts over sharing of the catch of Pacific salmon. In addition, the Salmon Enhancement Program is continuing to work hard to increase salmon production by supplementing natural reproduction with hatchlings and by improving habitat; and the Skeena Model Fishery pilot project is examining new ways of bringing commercial, Aboriginal, and recreational fishermen together in a cooperative effort to sustain the resource.

The Pacific Herring is an example of how a strong conservation framework and accurate biological research can contribute to managing marine fish stocks in a sustainable manner (Box 11.9).

New policies and legislation are being formulated. For example, the proposed Canada Oceans Act will facilitate the development of a national strategy for managing estuarine, coastal, and marine ecosystems. The national strategy will be based on the principle of sustainable development — that is, development that meets the needs of the present without compromising the ability of future generations to meet their own needs — and on the integrated management of activities in estuaries, coastal waters, and marine waters.

Box 11.8
Fishing vessels and techniques

On the Atlantic coast, the commercial fishing fleet can be divided into three categories: inshore, consisting of vessels of less than 45 feet (13.7 m) in length that fish using mainly fixed gear; midshore, consisting of vessels of 45–65 feet (13.7–19.8 m) in length that use fixed or mobile gear; and offshore, consisting of vessels that are primarily 150–170 feet (45.7–51.08 m) in length and fish using mobile gear. Inshore and midshore vessels are mainly owned by individual fishermen, whereas offshore vessels are owned by large companies. The small inshore vessels are more numerous than the mid/offshore ones: in 1990, 70% of registered vessel owners had vessels of less than 35 feet (10.6 m) in length. Approximately 93% of active fishermen in the Atlantic region operate from inshore or midshore vessels, but these account for only 54% of the amount of fish taken.

Inshore vessels generally provide far more support to the economies of local communities than does the offshore "industrial" fleet, a fact that has implications for the sustainable management of fisheries. Offshore vessels take primarily groundfish (but now shrimp and molluscs are increasingly important), whereas inshore and midshore vessels harvest groundfish and many invertebrate and pelagic species.

On the Pacific coast, the "inshore–offshore" categories are not applicable. Most of the 5 800 registered vessels occupy the 35- to 100-foot (10.6–30.48 m) range, with a few larger offshore trawlers.

Fishing gear can be generally categorized into "fixed" or "mobile" gear. Fixed gear includes traps of all kinds, anchored longlines (longlines with baited hooks attached at regular intervals), and set gillnets (curtains of netting in which fish become entangled). Mobile gear includes bottom and midwater trawls (towed bags of netting), purse seines (nets set around schools of fish), trolling gear (towed baited hooks), and drifting gillnets.

On the Atlantic coast, groundfish are mainly harvested by trawls, longlines, traps, and handlines, whereas the valuable lobster and crab fisheries are harvested with traps. On the Pacific coast, salmon are harvested by trolling gear, gillnets, and purse seine nets, whereas the various species of groundfish are harvested with trawls, longlines, and traps.

Following an intensive review of federal government programs in 1994, federal departments and the provinces began discussing a new framework for management of fisheries and aquatic resources in Canada. Under the proposed framework, the federal Department of Fisheries and Oceans would take all responsibility for oceans management, whereas responsibilities for inland waters would be shared between the federal Department of the Environment and the provinces. The federal government would delegate legislative authority for fisheries management to the inland provinces, while retaining authority over Aboriginal fishing rights. All levels of government in Canada are searching for improved ways of delivering programs in the mid-1990s, and further structural changes in aquatic resource management can be expected.

At the international level, Canada has strongly supported United Nations-sponsored conferences and other initiatives on fisheries, as described in the "Fisheries issues" section.

Conclusion

Canadian fisheries suffered acute and highly visible crises in the early 1990s. The collapse of the Atlantic groundfish stocks forced closure of fisheries that were the principal support of numerous coastal communities, resulting in widespread economic and social disruption. Media and public attention has been drawn to fisheries problems worldwide.

Many explanations have been provided for the current fisheries problems, but several key themes emerge: fishing capacity in excess of that required to take a biologically sustainable harvest (often expressed simply as "too many fishermen chasing too few fish"); the open-access management regime that encourages individuals to maximize their harvests; the challenges of assessing the abundance of invisible, mobile fish stocks with enough precision to determine appropriate harvest levels; and inadequate knowledge of the production characteristics of marine ecosystems and of the effects of environmental variability.

Table 11.9
Aquaculture tonnage and value produced

Main species	1991 Quantity (t)	1991 Value ($, millions)	1993 Quantity (t)	1993 Value ($, millions)	Outlook to year 2000 Quantity (t)[a]	Outlook to year 2000 Value ($, millions)[a]
Salmon	29 099	220.0	32 523	245.0	89 400	502.6
Trout	4 808	24.0	5 267	26.8		
Oysters	6 830	6.2	6 528	6.8	18 500	20.5
Mussels	4 046	0.5	5 175	5.7	35 000	32.0
Total	44 783	250.7	49 493	284.3	142 900	555.1

[a] Numbers for salmon and trout are presented together.

Source: Department of Fisheries and Oceans (1993b, 1995b).

With the exception of the shellfish fisheries, pollution and habitat degradation do not appear to have had major impacts on most marine fishery resources. However, the impacts observed on freshwater fisheries, and the limited but increasing impacts in coastal areas, should serve as a reminder that aquatic environments are highly sensitive. There is also concern about the impacts of fishing gear on habitat.

The fishing industry and governments are responding to the recent problems in a number of ways. Moratoriums on fishing and significant changes in management regimes have been initiated in response to the crises experienced; programs to reduce fishing capacity have been initiated to deal with these crises in the longer term. Fisheries research is intensifying in the areas of ecosystem dynamics, species interactions, and abundance assessment.

Furthermore, new management approaches are being developed based on a larger role for the harvesting industry in management and stronger mechanisms for partnership between industry and government. The Fisheries Resource Conservation Council is one such mechanism, and a number of other mechanisms are developing. Individual quotas have been introduced in an attempt to overcome the open-access problem; these have their own problems but show promise in certain situations. Fundamental changes in the fisheries management framework have been put in motion both nationally and internationally: nationally, with the tabling of the Canada Oceans Act, development of an Oceans Management Strategy, and discussion of marine and freshwater fisheries management responsibilities among federal and provincial government departments; and internationally, through the United Nations, with meetings leading to development of a management regime for high-seas stocks to complement the Law of the Sea developed in the 1970s and with development of a more responsible fishing strategy.

It is important not to lose sight of those fisheries that continue to perform well and to contribute to economic well-being and

Box 11.9
Pacific Herring: a management success story

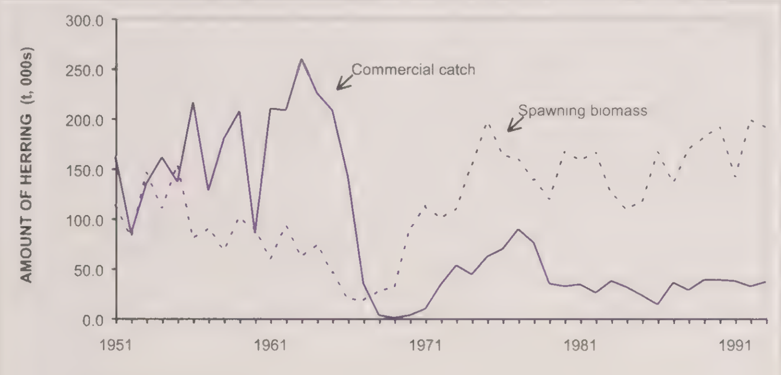
The Pacific Herring stock off Canada's west coast is highly valued internationally and provides employment for thousands of Canadians and a way of life for many coastal communities. In addition, the fishery contributes millions of dollars to the Canadian economy each year. Furthermore, this fish species occupies a key role in the marine food web of the region. Herring are a key fish prey of the Chinook Salmon, Pacific Cod, Lingcod, and Harbour Seals in southern B.C. waters. Herring eggs are also important food sources for migrating seabirds and Grey Whales and for invertebrates.

The herring fishery has seen hard times. By the mid- to late 1960s, nearly all the major herring stocks had been discovered, and most of the older spawning fish had been removed from the population by overfishing (Fig. 11.B1). The commercial fishery could not be sustained and collapsed. As a result, in 1967, the commercial fishery was closed by the federal government for four years. The closure of the commercial fishery was a crucial step in the attempt to rebuild the stocks. Fortunately, herring belong to a group of fish species that can recover quickly from a reduced population size. The stock did rebuild, and, in 1972, a new fishery began to harvest herring for its roe. The roe fishery catches far less fish (only 35 000 t per year) than the previous fishery for herring (which caught quantities in excess of 250 000 t per year) (Environment Canada 1994a).

By closing the fishery for stock rebuilding and by switching to a new fishery, stocks have been sustained, and the landed value has increased (Fig. 11.B2). As a result, Canada is now a major exporter of herring roe to Japan, the world's only market. In 1991, herring contributed an average $214 500 to the gross income of a herring boat; in 1993, the wholesale market for herring roe was $180 million. Furthermore, the roe fishery has many spinoffs for B.C. fishery workers and processors, resulting in thousands of additional jobs in the labour-intensive processing of the roe and other herring products (Environment Canada 1994a).

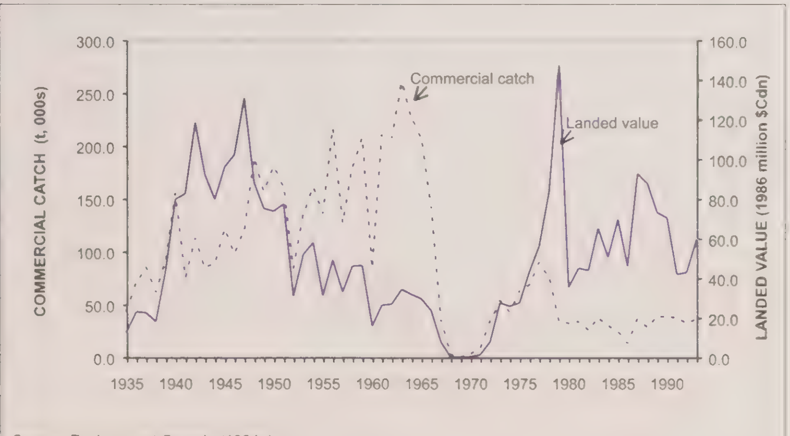
community stability in Canada: the Atlantic invertebrate (lobster, shrimp, Snow Crab) and Pacific Herring fisheries, for example. Indeed, despite the well-publicized crises in the fisheries, the total landed value of Canada's fisheries declined remarkably little in the early 1990s. Aquaculture production is growing at a prodigious rate, farmed fish have become common in Canada's fish markets and are contributing to export revenues, new species are being brought into culture, and new techniques are developing rapidly. Environmental concerns with the rapid growth of aquaculture are being addressed as the industry grows.

Figure 11.B1
Commercial catch of Pacific Herring in relation to spawning biomass, 1951–1993



Source: Environment Canada (1994a).

Figure 11.B2
Landed value in relation to quantity of commercial catch of Pacific Herring, 1935–1993



Source: Environment Canada (1994a).

Minerals, Metals, and Mining

Introduction

Minerals and metals are essential to the everyday lives of Canadians. The filament in a light bulb, a computer chip, and a dentist's drill — all are made from minerals and metals and are an integral part of the Canadian lifestyle. As we move towards the 21st century, more and more people are concerned about this Canadian lifestyle, with its attendant environmental costs. Mining and the associated processing of metal and nonmetal minerals affect the environment, and public concern about the environmental impacts of mining has been rising over the past two decades. Governments and the mining industry have responded with legislation, policy, regulations, voluntary initiatives, and joint research projects to reduce the environmental impacts of mining.

The Canadian mineral industry can be characterized by the following four stages of processing activity:

I. primary metal production (mining and concentrating);
II. metal production (smelting and refining);
III. minerals and metal-based semifabricating industries;
IV. metal fabricating industries.

This component of Chapter 11 focuses on the contribution of mining to Canada, the environmental problems of mining, and the progress that the industry has made in moving towards sustainable development in the past five years. The emphasis here is on non-energy-related minerals, in stages I and II of the mineral industry.

Mining and its contribution to Canada

Mining has played an important part in the history of Canada's development, from the coal mines of Nova Scotia to the Yukon gold rush. Songs and stories about miners and mining disasters and discoveries have established a rich culture around a long-lived and viable mining industry. The discovery of nickel, copper, and other minerals was a key factor in the emergence of the Great Lakes Region as the economic engine of both Canada and the United States. Value-added by the mining industry continues to be a significant part of Canada's national economy. Export dollars are particularly important. All employment provided by the mining industry and the communities that flourish as a result

are of direct importance to a large number of Canadians. The mining industry continues to generate these benefits for Canadians and will remain a large part of Canada's future economy.

Canada's mines can be categorized by the type of materials mined. Table 11.10 lists these categories and the percentage of each category's contribution to total Canadian mineral production in 1995.

As of January 1995, there were 558 producing mining and quarrying establishments operating in Canada. As can be seen from Table 11.11, this is comparable to the 1990 figure. The percent contribution of mining to Canada's economy has remained steady over the 1990–1995 period; as shown in Figure 11.27, mining is economically significant across the entire country. Mining as an industry has had to become more efficient in order to remain competitive internationally. Although the need to be competitive coupled with the recession experienced in the early 1990s resulted in declining employment levels in the mining industry, recent surveys show that employment increased in 1994 and 1995 (Table 11.12).

Mining plays an important role in the Canadian economy (Box 11.10) and makes a significant contribution to GDP (Fig. 11.28).

The changing demand for metals and recycling

Continued population growth coupled with a desire for more material goods has resulted in a continuing increase internationally in the demand for new minerals and metals, although at a lower rate than was evident in the postwar period. Changes in technology, market trends, and the globalization of mining companies are some of the factors that are changing the demand for various metals, as reflected in primary metal production figures. Figure 11.29 shows trends in the production of the principal refined metals in Canada between 1965 and 1994.

Recycled minerals and metals have economic value, and an increasing market for recycled mineral and metal products is helping the environment: "Metal recycling embodies the spirit of sustainable development for metallurgical industries" (Smith 1995). Reuse and recycling practices and the long life span of minerals and metals have the potential to diminish primary extraction by increasing the stock of extracted minerals and metals.

Scrap metals and recycled metals travel the same metallurgical route as primary metals in smelters and refineries. Because Canada's primary metals industry has developed a large metal smelting and refining capacity, Canada is in an excellent position for metal recycling. Most metal products produced in Canada are made from a mixture of primary and recycled metals (Natural Resources Canada 1995d). The following are recycling facts relating to several key minerals produced in Canada:

- About 50% of the 15 million tonnes of iron and steel produced every year in Canada comes from recycled iron and steel scrap.
- More than 90% of the lead consumed in Canada can be economically recycled. Secondary lead production represented approximately 40% of total Canadian refined lead production in 1995. Worldwide, lead production from recycled materials surpassed primary production for the first time in 1989.
- World consumption of refined copper from primary and secondary sources was 11.9 million tonnes in 1995, up from 11.6 million tonnes in 1994. In 1995, 4.6 million tonnes of scrap copper were recovered, of which 3.1 million tonnes were used directly by consumers.
- Scrap copper accounts for approximately 40% of the raw material input of refined copper production and consumption worldwide.
- The automotive industry accounts for approximately 80% of the end use of secondary aluminum. In 1971, an average of 35 kg of secondary aluminum was used in the production of each new car. By 1994, this figure was 68 kg of aluminum per car.
- In 1994, 29.7% of the world's refined aluminum production came from recycled sources (Smith 1995).

Compared with primary production, metal recycling has significant environmental benefits. There is less demand for raw material, more efficient use of mineral resources, and increased energy conservation (Natural Resources Canada 1995d). Energy savings are realized through the decreased quantity of fossil fuels used to generate electricity or operate smelters. Fossil fuel combustion produces carbon dioxide, sulphur dioxide, and nitrogen oxides (NOx). Recycling reduces these air emissions as well as discharges of effluents from primary extraction operations.

Recycling of the four most commonly recycled nonferrous metals to produce the raw metals results in the following energy savings: aluminum, 95%; copper, 85%; lead, 65%; and zinc, 60%. Producing

Table 11.10
Categories of minerals and their contribution to total Canadian nonfuel mineral production, 1995

Category	Example	% of total value of 1995 nonfuel mineral production in Canada
Metals	Gold, silver, lead, copper, nickel, zinc, molybdenum, iron	68.8
Nonmetals	Asbestos, gypsum, potash, salt	16.3
Quarries	Granite, limestone, marble, sandstone, slate, aggregates for construction (sand, gravel)	14.9

Note: Total value of Canadian nonfuel mineral production for 1995 was $17.4 billion.
Source: Minerals and Metals Sector, Natural Resources Canada.

steel from recycled materials results in energy savings of 74% compared with primary production (Smith 1995).

Over 1 000 companies are involved in the Canadian scrap metal recycling industry, which directly employs about 20 000 people. Recycling companies in Canada handle over 11 million tonnes of metals annually, valued at more than $3 billion (Smith 1995). During 1994, Canadian trade in recyclable metals exceeded 4 million tonnes, valued at over $2 billion (Table 11.13).

The mining process

The manner in which a mineral or metal occurs in nature determines the type of mining operation required, the cost needed to extract it, and the amount of waste produced in the process of extracting, separating, and concentrating it (Government of Canada 1991). There are two fundamental types of mining activity: surface mining and underground mining.

Surface mining includes "open pit" mining (surface mining that recovers ore from deposits by making a progressively larger and deeper pit to remove overburden and waste rock and recover or extract ore) and "strip mining" (surface mining from which the sought material, e.g., coal, sedimentary iron ore, or other relatively flat-lying material that is not buried too deeply, is exposed by shovels or draglines that cast the waste materials into the cut made in the preceding extractive removal of the ore or coal). Placer mining is a form of surface mining whereby river- and streambeds are mined for eroded particles of minerals. This type of mining occurs mainly in the Yukon, with a small amount of activity in British Columbia. It began in Canada during the gold rushes of the last century, with the simple process of panning for gold. In 1992, over 70% of mineral production in Canada (excluding industrial minerals) was from surface mining operations (Ripley et al. 1996).

Underground mining, as the term implies, is the process of extracting the desired material from depths that cannot be economically or physically accessed and recovered from the surface. The process involves the sinking of shafts or declines or the driving of horizontal tunnels (adits) into the ore zone, drilling, blasting, and collecting the broken ore, and hoisting or hauling it to the surface by ore hoists or wheeled haulage vehicles.

In general, there are four phases of mining, as described in Table 11.14 and in the following sections.

Exploration

Mineral exploration involves gathering geophysical, geochemical, and geologic information, and it takes place in all provinces and territories of Canada. When mineral deposits of potential economic value are discovered, a claim may be staked granting exclusive entitlement to further explore, develop, and acquire the mineral rights under claim and develop that claim through to production (Natural Resources Canada 1995d). Normally, 4–7 million hectares are staked annually in Canada. The largest mineral rush/staking in Canadian history started in 1991 and was for diamonds in the Northwest Territories. In 1992, this diamond exploration boom increased the area of mineral claims staked in Canada to an all-time annual record of 33 million hectares, which dropped to 27 million hectares in 1993 and to 16 million hectares in 1994, staying at this level in 1995 (Bouchard and Cranstone 1994; G. Bouchard, Natural Resources Canada, personal communication).

Table 11.11

Producing mining establishments in Canada, 1990 and 1995[a]

	Nfld		P.E.I.		N.S.		N.B.		Que		Ont		Man.		Sask.		Alta		B.C.		Yukon		N.W.T.		Total	
Mineral group	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995	1990	1995
Metals	4	3	–	–	2	[illegible]	[illegible]	2	32	29	35	24	4	5	[illegible]	4	–	–	18	14	[illegible]	1	6	[illegible]	[illegible]	88
Nonmetals																										
Asbestos	1	1	–	–			–	–	2	2		–							5						4	[illegible]
Potash	–	–	–		–	–	2	2		–		–		–	15	9	–	–			–		–		12	11
All others[b]	4	2		3	8	8	14	20	[illegible]	[illegible]	15	15	[illegible]	3	8	8	4	5	[illegible]	[illegible]					[illegible]	[illegible]
Structural materials[c]	6	5	–		11	8	8	7	108	136	92	[illegible]	11	11	2	7	20	32	19	22	–	–	–	–	211	[illegible]
Energy-related materials[d]																										
Uranium	–		–					–	–		2	[illegible]		–	[illegible]	[illegible]									7	4
Coal	–	–	–	–	3	[illegible]	1	1			–		–	–	5	[illegible]	11	12	8	8					[illegible]	[illegible]
Total	15	11	–	3	24	21	28	32	[illegible]	[illegible]	144	[illegible]	18	[illegible]	41	[illegible]	35	48	44	47	[illegible]	1	6	[illegible]	[illegible]	[illegible]

[a] Establishments refer to the smallest operating unit from which, among other things, data can be provided on the value of output. An establishment may have more than one operating mine. Figures are as of January both years.

[b] Included 55 peat operations in 1990: 33 in Quebec, 14 in New Brunswick, and 8 in six other provinces; and 66 in 1995: 32 in Quebec, 21 in New Brunswick, and 13 in other provinces.

[c] There are thousands more operations producing sand, gravel, and stone. Many other organizations that operate producing sand and gravel pits an[illegible]e quarries (including, for example, municipalities and construction companies) are in other industrial classifications and are not included in this table. The increase in [illegible]mber of establishments is partly due to improved survey methodology.

[d] Energy-related materials are discussed in the "Energy use" component of this chapter.

Source: Government of Canada (1991); K. Kokkinos, Minerals and Metals Sector, Natural Resources Canada, personal communication

Mining and milling

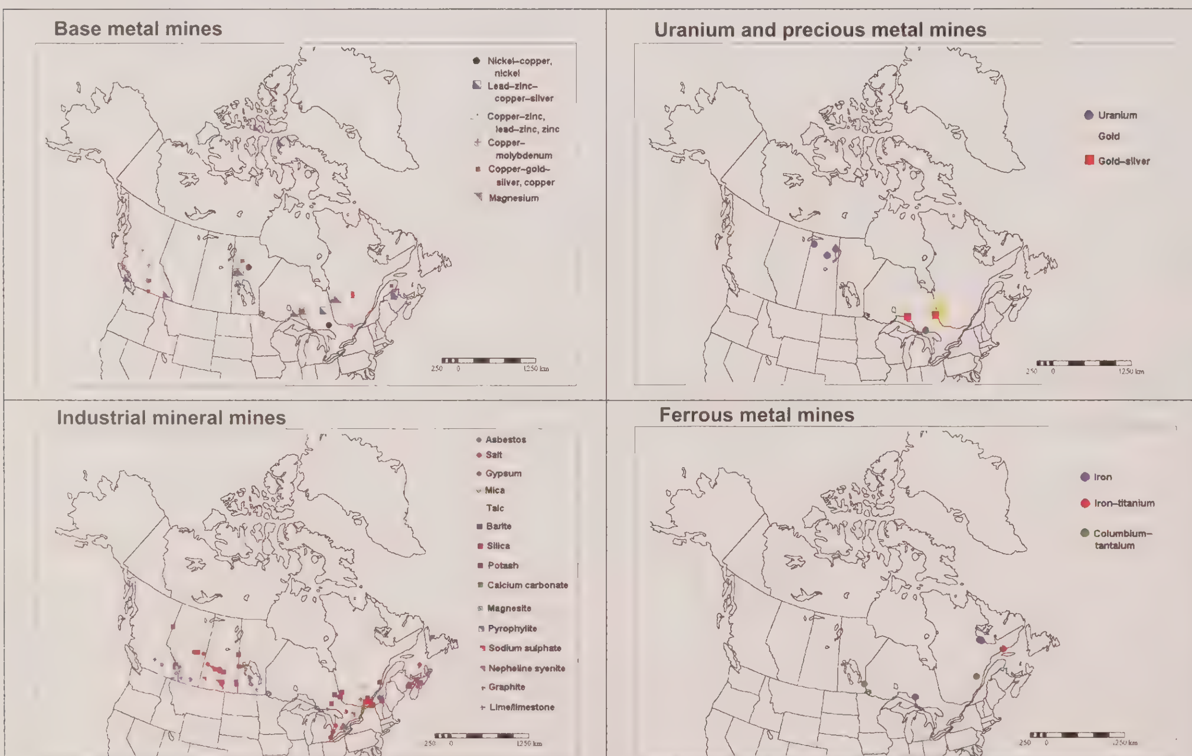
This phase of mineral production involves mine site development, followed by extraction of ore from the deposit, milling of the ore (i.e., crushing, grinding, and size classification), and separation of the minerals from impurities using chemical or mechanical processes. Many nonmetallic commodities (e.g., sand, limestone, and gravel) require only basic processing or crushing. Other nonmetallic minerals (e.g., asbestos, talc, graphite, and potash) require further processing prior to being used or exported. Most metal ores require crushing and grinding, then additional treatment with chemical or biological reagents to extract the desired minerals, thereby producing a fine mineral concentrate, which is shipped to a smelter for the next stage of recovery. The amount of concentrate produced per tonne of ore is small in comparison to the amount of waste. For example, a copper mine with 2% copper per tonne of ore produces less than 66 kg (approximately 57 kg if recovery rates average 85%) of concentrate at 30% copper, with more than 934 kg of finely ground rock produced as waste called tailings. The smelter then produces 16 or 17 kg of metal from this concentrate, with the rest going out as waste called slag. Ignoring other minerals (fluxing agents) added to aid in the smelting process and waste rock that had to be moved to access the ore in the first place, it is clear that, in this example, only about 1 part in 60 of the original tonne of ore ends up as usable metal. The ore of some mines is richer, and the relative quantities of waste vary accordingly. To keep the situation in perspective, it is important to realize that, although a large portion of the material moved by a mining operation ends up being discarded as waste, the bulk of this waste is nothing more than either broken or finely ground rock.

Smelting and refining

Metals account for more than half of the value of Canada's mineral production and are smelted and refined using high-temperature processes (e.g., pyrometallurgy) or aqueous processes (e.g., hydrometallurgy). Figure 11.30 shows the location of major nonferrous smelters and refineries in Canada. Smelting and refining produce ingots, bars, sheets, and other solid forms

Figure 11.27

Principal mining areas of Canada, 1995



Source: Natural Resources Canada database; Natural Resources Canada (1996).

Table 11.12
Employment in the Canadian mineral industry, stages I and II, 1961–1995

Year	Numbers employed						
	Stage I				Stage II		
	Metal mines	Nonmetal mines	Structural materials	Total non-fuel mining	Smelting/ refining	Iron and steel mills	Total primary metals
1961	58 591	11 003	5 235	74 829	29 938	34 749	64 687
1962	58 243	11 408	5 514	75 165	29 693	36 593	66 286
1963	57 119	11 661	5 686	74 466	28 516	38 196	66 712
1964	57 648	11 727	6 044	75 419	30 153	41 505	71 658
1965	60 942	12 116	6 248	79 306	31 835	44 274	76 109
1966	61 670	12 422	6 312	80 404	34 237	45 999	80 236
1967	61 728	13 077	5 779	80 584	34 764	44 203	78 967
1968	63 369	13 673	5 836	82 878	34 710	44 634	79 344
1969	60 550	14 322	5 692	80 564	33 376	42 954	76 330
1970	66 590	15 150	5 510	87 250	37 298	49 169	86 467
1971	66 012	15 105	5 328	86 445	36 445	49 601	86 046
1972	61 994	14 866	5 154	82 014	33 829	49 758	83 587
1973	66 134	15 391	5 276	86 801	32 396	53 008	85 404
1974	70 038	16 198	6 197	92 433	35 249	54 253	89 502
1975	69 161	13 703	6 382	89 246	35 577	54 003	89 580
1976	68 269	15 649	5 685	89 603	34 246	51 978	86 224
1977	67 242	16 608	5 190	89 040	35 647	52 709	88 356
1978	56 447	16 035	4 847	77 329	32 652	56 669	89 321
1979	58 960	16 770	4 692	80 422	32 869	59 167	92 036
1980	66 118	16 979	4 461	87 558	36 137	61 238	97 375
1981	68 712	16 391	4 183	89 286	38 011	56 543	94 554
1982	61 503	13 680	3 491	78 674	33 215	52 330	85 545
1983	52 194	13 170	3 403	68 767	31 788	47 693	79 481
1984	52 683	13 698	3 560	69 941	31 752	48 899	80 651
1985	48 672	12 974	3 941	65 587	30 567	47 685	78 252
1986	46 487	12 376	4 887	63 750	29 058	46 461	75 519
1987	45 496	12 181	5 738	63 415	29 397	46 493	75 890
1988	48 277	11 679	5 917	65 873	30 099	48 259	78 358
1989	49 405	11 714	5 881	67 000	30 651	46 738	77 389
1990	45 248	11 515	5 376	62 139	30 573	39 120	69 693
1991	42 092	10 812	5 026	57 930	28 817	38 126	66 943[c]
1992	37 774	10 419	4 338	52 531	27 837	35 268	63 105[c]
1993	34 738	10 500	4 219	49 457	26 175	33 327	59 502[c]
1994	34 013[a]	10 451[a]	5 379[a]	49 843[a]	25 305[a]	31 426[a]	56 732[c]
1995	34 950[b]	10 795[b]	5 973[b]	51 718[b]	26 591[b]	32 571[b]	59 162[c]

Notes: Stage I = primary metal production (mining and concentrating).
Stage II = metal production (smelting and refining).
Numbers may not add to totals owing to rounding.

[a] Preliminary.
[b] Estimated.
[c] Change is partially due to change in Standard Industrial Classification in 1991.

Source: Natural Resources Canada (1995c); unpublished data, Minerals and Metals Sector, Natural Resources Canada.

of the raw (elemental) metal, which are transported to production facilities for final fabrication of goods. The pyrometallurgical processes can emit gases and particulate matter into the air unless they are captured by air pollution control equipment.

Post-operational waste management
Eventually, the ore in a deposit will be depleted or it will become uneconomical to continue mining, and the mine will be closed. During operation, a significant amount of waste material and tailings will have been generated. These deposits and old mine workings must be stabilized and made safe, preferably in a way that will facilitate other uses over the long term. In some cases, a sufficiently high degree of physical and chemical stability can be achieved to allow the site to be safely closed out with no ongoing surveillance or treatment. In other cases, however, surveillance and management must continue indefinitely. In these latter cases, ongoing costs can be significant. To minimize post-operational costs, the mining industry is increasingly attempting to integrate closure requirements into the initial design of mine operations. This approach amounts to a full life cycle approach, which is emerging as a key part of designing for sustainability but is more often associated with product manufacturing. Pioneering work on design-for-closure in the mining industry dates from the 1970s, when it was applied in the design of the Cinola Mine, a gold property in the Queen Charlotte Islands, British Columbia.

Environmental impacts of mining

Each phase of mining has potential environmental impacts, as outlined in Table 11.15.

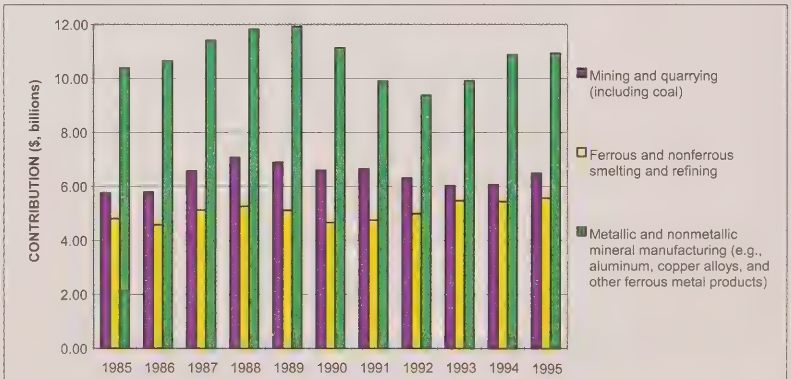
Exploration
Exploration for minerals normally begins with the extensive geological mineral records that have been compiled over the past century in Canada. These help determine areas of high mineral potential. When this process is complete, geoscientists and prospectors begin gathering more specific information about the mineral potential of a given area, using remotely sensed data, such as photos taken from low-flying aircraft, and ground-based exploration methods. Computers and geographic information systems (GIS) also assist in this process (Ripley et al. 1996). A small proportion of areas advance beyond these environmentally neutral stages of exploration. Advanced exploration may use trenching and drilling, and access roads, airstrips, and exploration camps may eventually be constructed, with increasing potential for impacts on the environment. Very few mines are actually developed compared with the amount of exploration work that takes place.

Box 11.10
The Canadian mineral industry and its economic significance, 1995

- *Canada is the world's largest mineral exporter; the four stages of the industry (minerals and mineral products including coal, but excluding mineral fuels) provide 16.4% of Canada's total exports and contribute $11.7 billion to the trade balance.*
- *On a volume basis, in 1994 Canada ranked first in the world in the production of uranium (15.1%), zinc (28.2%), and potash (36.1%) and second in the production of nickel (17.3%), cadmium (11.9%), asbestos (19.1%), and elemental sulphur (22.0%). It ranks among the top five producers of titanium concentrates, primary aluminum, gypsum, copper, platinum group metals, cobalt, molybdenum, gold, and lead.*
- *Based on the value of production, Ontario (30%), Quebec (16%), and British Columbia (18%) account for over 64% of Canadian mineral production (including metals, nonmetals, construction materials, and coal).*
- *The industry employs about 341 000 persons in non-fuel-related manufacturing (including persons employed in coal mining): 61 000 in nonfuel mining, 59 000 in primary metals smelting and refining, 88 000 in nonfuel semifabrication, and 133 000 in metallic mineral manufacturing. Mining is the employment mainstay for over 115 communities.*

Source: Natural Resources Canada (1995b); unpublished data, Minerals and Metals Sector, Natural Resources Canada.

Figure 11.28
The contribution of mining and related industries to Canada's gross domestic product, 1985–1995, at factor cost at 1986 prices



Note: Data for 1995 are estimated.

Source: Pilsworth and Kokkinos (1995); unpublished data, Minerals and Metals Sector, Natural Resources Canada.

The major environmental impact of mineral exploration stems from the construction of exploration roads in previously unroaded areas. One impact created by these roads is erosion, which may cause disruption to habitats of fish. A larger impact comes from opening up access to potentially sensitive wilderness areas, such as alpine meadows or Caribou calving grounds. Hunting, wilderness tourism, guides and outfitters, and other nonindustrial users may cause significant environmental impacts, from noise to harassment of wildlife.

Mineral exploration also raises the issues of land use and land access. Box 11.11 describes these issues, and a case study on the Tatshenshini/Alsek river region of northern British Columbia is presented in Box 11.12.

Improved technology and increasing sensitivity to environmental concerns mean that the majority of exploration need cause little or no environmental impact compared with the other phases of mining. Furthermore, data and information generated in the exploration phase can provide useful input to subsequent environmental assessment.

Mining and milling

The most significant physical disturbance of a mine site takes place during development, including the construction of roads and buildings, the sinking of mine shafts, and the stripping of surface vegetation, soil, and waste rock to form a working area or to expose the ore body for surface mining. The greatest amount of equipment movement, disturbance, dust, and noise usually occurs during mine construction (Marshall 1982).

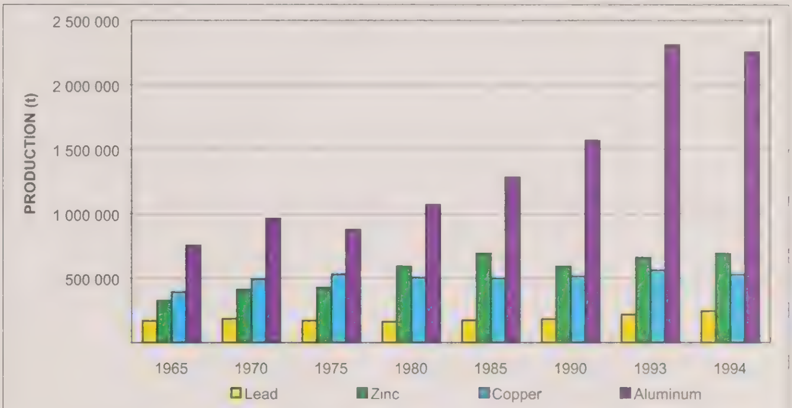
Subsequently, during mine operation, the main potential environmental issue is the type of effluent discharged from the tailings and waste rock to surface water and groundwater. If the effluents are not treated or acid generation is not prevented or controlled, these waters can be acidic in nature and contain concentrations of heavy metals. Depending on the ores mined and processed, these waters may also contain organic compounds, cyanide from gold milling, or ammonia (NH_3) compounds. All metal mines in Canada, however, must comply with effluent concentration regulations, guidelines, licences, or certificates of approval issued by federal, provincial, or territorial government authorities.

Acid mine drainage/acid rock drainage

Most metal mines in Canada contain sulphide minerals, particularly iron pyrite (fool's gold), in natural association with the desired minerals. When these sulphide minerals are exposed to air and moisture, oxidation occurs, resulting in the generation of sulphuric acid. Because mining leaves waste that consists largely of small pieces of broken waste rock and finely ground tailings, it dramatically increases the surface area that can be subjected to this process. If the rock has a natural buffering capacity (i.e., carbonate minerals), the acid generated will be neutralized until either the buffering capacity or the

Figure 11.29

Trends in the production of principal refined metals in Canada, 1965–1994[a]



[a] Production of metal from all sources, including metal derived from secondary materials at primary refineries.
Source: Natural Resources Canada database.

Table 11.13

Canadian exports and imports of metal recyclables, 1991–1994

	1991		1992		1993		1994	
	Quantity (t)	Value ($, 000s)	Quantity (t)	Value ($, 000s)	Quantity (t)	Value ($, 000s)	Quantity (t)	Value ($, 000s)
Total recyclable exports	1 821 586	769 545	1 872 389	833 904	2 235 526	868 758	2 436 628	1 114 065
Total recyclable imports	1 125 139	670 535	1 742 656	770 930	1 953 224	1 136 336	2 350 165	1 239 076

Note: Values for 1994 are estimated.

Source: Smith (1995).

acid-generating potential is consumed. The most significant problem with acid generation is that it may accelerate over time and, once begun, is almost impossible to stop. Certain microorganisms that feed on sulphur, particularly *Thiobacillus ferrooxidans*, accelerate the production of acid (Ripley et al. 1996). Increased acidity promotes the mobilization of contaminants such as heavy metals. This set of processes and the acidic effluents that result are grouped into what is known as "acid mine drainage" or "acid rock drainage." The latter term originates from the fact that this phenomenon is not necessarily confined to mining activities but can occur wherever sulphide-bearing rock is exposed to air and water.

Acidic drainage is the most serious environmental problem facing the global metal mining industry. Although steps can be taken to slow the process or treat the acidic effluent, it is difficult to prevent completely.

The Canadian mining industry generates approximately 650 million tonnes of tailings and waste rock annually, half of which are from sulphide ore operations. Table 11.16 provides estimates of all mine wastes as well as acid-producing and potentially acid-producing mine wastes in Canada. Technologies to reduce and prevent acidic drainage are being researched and developed in Canada under the Mine Environment Neutral Drainage (MEND) program, a cooperative program between industry and both federal and provincial governments (MEND is described in more detail in this component, under the section "Cooperative efforts to address environmental concerns"). Promising techniques developed under MEND for preventing or controlling acidic drainage are summarized in Box 11.13.

Heavy metals

The major environmental problem caused by acidic drainage is the accelerated release of heavy metals from waste rock and tailings into surface water and groundwater. Effluents from metal mines can contain metals such as arsenic, cadmium, copper, iron, lead, nickel, and zinc at various concentrations (these limits are prescribed by government). All of these can have harmful effects on downstream aquatic life, especially fish. A significant problem with heavy metals is the potential for redistribution of metals in the environment and the subsequent changes in concentrations and forms of metals or their compounds in natural media. Metals themselves are not highly reactive; however, if a metal or an inorganic metal compound dissolves, the resulting metal cations will be reactive. Some metals, such as mercury, may form organometallic compounds through biological processes. Both the dissolution of metals and the incorporation of metals into organic compounds may result in increased bioavailability of metals or in bioaccumulation and toxicity, which, in turn, could lead to adverse effects within ecosystems. Equally so, metal cations may be removed from the aquatic environment through reactions that render them stable inorganic compounds.

The risk posed by heavy metals in fresh water depends both on the metal concentration and on the characteristics of the affected organisms. Mine effluents containing heavy metals are commonly treated with lime to precipitate the dissolved metals in the form of hydroxides. This type of treatment is generally effective at removing over 90% of metals and suspended sediments from the mill effluent.

In 1977, the federal Metal Mining Liquid Effluent Regulations (MMLER) and Guidelines (MMLEG) came into force. The objective of these measures is to ensure that base metal, uranium, and iron ore mines operating in Canada apply the most practical and recent technology to ensure that their liquid effluents meet regulatory concentration limits. Provincial and territorial governments play a major role in regulating mine effluents through their regulations, codes, guidelines, and certificates of approval, which commonly set lower limits and apply to more parameters than do the MMLER. In addition, the provincial or territorial control requirements can be set to recognize and protect site-specific sensitive receiving environments.

Organic compounds

Base metal milling commonly uses a flotation process, whereby chemicals are mixed with ore in water solutions to separate the desired mineral from the ore. The tailings are normally filtered, then washed and repulped to remove most of the reagents; however, some flotation reagents will remain in solution in the tailings. Flotation reagents used in base metal concentrators may include kerosene, organic flotation agents, and sulphuric acid. Residual reagents can be found both in the effluents from a mill and in stored tailings. Once tailings solids have settled, the tailings effluent meeting regulatory require-

Table 11.14
The four phases of mining

Phase	Key activities
Exploration	• prospecting • geochemical and geophysical surveys • drilling and trenching • staking mining claims
Mining and milling	• feasibility and engineering design studies • public review • mine construction and pre-production • extraction and crushing and/or grinding of ore • flotation or chemical concentration of ore
Smelting and refining	• subject mineral concentrate to high heat to form ingots, bars, etc. of pure metal or alloy
Post-operational waste management	• mine reclamation and abandonment

Figure 11.30
Nonferrous smelters and refineries, 1995

1. **Kitimat:** aluminum ingots and alloys
2. **Houston:** ammonium dimolybdate, molybdenum trioxide
3. **Endako:** molybdenum trioxide
4. **McLeese Lake:** copper cathodes
5. **Port Coquitlam:** tungsten, titanium and tantalum–niobium (columbium) metal powders and carbides
   Burnaby: secondary lead
6. **Trail:** zinc, lead, silver, gold, cadmium, bismuth, tin, indium, germanium, antimonial lead, mercuric chloride, copper matte, sulphuric acid, ammonium sulphate, sulphur, liquid sulphur dioxide, high-purity metals
7. **Fort Saskatchewan:** nickel, cobalt, copper sulphide, ammonium sulphate
8. **Flin Flon:** copper anodes, zinc, cadmium
9. **Thompson:** nickel, copper matte, precious metal residue, cobalt oxide
10. **Blind River:** uranium trioxide
11. **Timmins:** zinc, copper cathodes, cadmium, indium, sulphuric acid
12. **Noranda:** copper anodes, sulphuric acid, precious metals
13. **Sudbury (Falconbridge):** nickel–copper matte, containing gold, silver, platinum group metals
    Sudbury (Inco): nickel oxide (sinter), nickel pellets and powder, nickel sulphate, copper cathodes, gold, silver, selenium cake, tellurium dioxide cake, platinum group metals (in residues), sulphuric acid, liquid sulphur dioxide, sulphur
14. **Brampton–Toronto–Mississauga:** gold, silver, secondary lead
    Burlington: secondary zinc
    Stoney Creek: secondary zinc
15. **Port Colborne:** utility nickel, nickel oxide, nickel–chromium–iron ingots, platinum group metals (in residues), cobalt oxide, electrolytic cobalt
16. **Port Hope:** uranium hexafluoride, uranium dioxide, uranium metals and alloys
17. **Haley:** magnesium, magnesium alloy ingots, calcium alloys
    Pembroke: strontium
18. **Ottawa:** gold, silver
19. **Beauharnois:** aluminum ingots and alloys
    Valleyfield: zinc, cadmium, sulphuric acid
20. **Montreal-East:** copper (cathodes, billets, cakes, ingots, and bars), gold, silver, tellurium, selenium, nickel sulphate, copper sulphate, platinum group metals
    Ville-Ste-Catherine: secondary lead
21. **Sorel:** titanium dioxide slag, iron
22. **Bécancour:** aluminum ingots and alloys, magnesium ingots and alloys
    Deschambault: aluminum ingots
    Shawinigan: aluminum ingots and alloys
23. **Grande-Baie:** aluminum ingots and alloys
    Isle-Maligne: aluminum ingots and alloys
    Arvida: aluminum ingots and alloys, alumina, aluminum chemicals, composites
    Laterrière: aluminum ingots and alloys
24. **Baie-Comeau:** aluminum ingots and alloys
25. **Murdochville:** copper anodes, sulphuric acid
26. **Sept-Îles:** aluminum ingots
27. **Belledune:** lead, silver, copper matte, bismuth, sulphuric acid, antimony, diammonium phosphate

Source: Natural Resources Canada (1996)

ments may be discharged to natural water bodies. Regulations may be applied by provincial or territorial authorities, depending on the various jurisdictions.

Cyanide

Cyanide compounds may be lethal to fish, such as trout, at concentrations as low as 0.04 mg/L. Gold mines are the major users of cyanide, which is employed in the milling process; cyanide is also used in base metal ore flotation. The latter operation uses cyanide in such small amounts that it can naturally degrade in flotation tailings effluents. Cyanide and cyanide–metal compounds may be removed from gold mill effluent either by natural degradation or by a treatment process, prior to discharge to the tailings ponds. A treatment process may be required because the retention time in tailings ponds may not be long enough for the cyanide to break down naturally.

Several processes have been and are being developed to treat gold mill effluents and tailings pond waters that have high cyanide concentrations: the Inco sulphur dioxide–air oxidation process, hydrogen peroxide oxidation, AVR (acidification, volatilization, regeneration) in its several variants, ion exchange, and biodegradation. With these technologies, most of the cyanide (including metallocyanide complexes) can be destroyed or recovered. These metallocyanides are more stable and difficult to treat and may end up in the aquatic environment. The effluents from the approximately 50 Canadian gold mines are now subject to limits on total cyanide specified in provincial regulations, permits, and licences and territorial Water Board licences (Blakeman et al. 1995).

Table 11.15

Potential environmental impacts of each phase of mining

Mining phase	Potential impacts
Exploration	• generally low or no impact • when exploration reaches a stage of requiring trenching, drilling, or road access, habitat disturbance increases and the discharge of contaminants can occur
Mining and milling	• discharge of acid mine drainage that contains contaminants that are released to surface water and groundwater; particular concerns are related to: - heavy metals originating in the ore and tailings (can be accelerated by naturally occurring acid generation) - organic compounds originating in the chemical reagents used in the milling process - cyanide, particularly from gold milling processes - ammonia • alienation of land as a result of waste rock piles and tailings disposal areas • increased erosion; silting of lakes and streams • dust and noise
Smelting and refining	• discharge of contaminants to air, including heavy metals, organics, and SO_2 • alienation of land as a result of slag • indirect impacts as a result of energy production (smelting and refining take most of the energy used by mining processes)
Post-operational waste management[a]	• continuing discharge of contaminants to groundwater and surface water (particularly heavy metals when naturally occurring acid generation exists) • alienation of land and one-time pulse discharge of contaminants and sediment to water as a result of dam failure

Note: A particular concern centres on the responsibility for orphaned mine sites; liability falls to society through the government.

[a] Does not apply everywhere.

Ammonia

The free or un-ionized form of ammonia is toxic to fish, especially at high pH and low temperature. The mining sector's contribution to ammonia emissions is relatively minor compared with the contributions of other sources, such as agriculture (feedlots and fertilizer) and municipal waste. The presence of ammonia in mine and mill effluents is generally attributed to the use of ammonia as a pH regulator (e.g., in uranium precipitation) or as a reagent or leaching agent (e.g., in copper or nickel processing); the use of ammonia or amines as flotation reagents in milling; the process used to destroy cyanide in gold mill and tailings pond effluents (i.e., ammonia is one of the by-products); and the use of ammonia-based explosives (e.g., ammonia nitrate and fuel oil, or ANFO). The improved use and handling of ANFO have contributed to the reduction of ammonia levels in mine effluents.

The Canada Centre for Mineral and Energy Technology (CANMET) formed the Ammonia Control Consortium to develop and demonstrate a generic process for ammonia destruction in typical mine and mill effluents. The consortium concluded that economical ammonia treatments must be developed on a site-specific basis. These treatments will rely mainly on natural degradation and best management practices owing to the low concentration of ammonia in large volumes of effluent (K.G. Tan, CANMET, Natural Resources Canada, personal communication).

Smelting and refining

Smelting and refining operations are used to produce most base metals (copper, lead, zinc, and nickel), all ferrous metals (iron and steel), and aluminum.

The environmental aspects of ferrous metal smelters are described in Box 11.14. Environmental concerns associated with aluminum smelting are noted in Chapter 1, Box 1.4.

The blast furnaces, basic oxygen furnaces, sintering, coke-making and by-product operations of the integrated producers and electric arc furnaces are the major source of air emissions from the Canadian steel industry. The coke-making operation has been described as "the most problematic [in the production of primary iron] in terms of emitting hazardous substances to the environment" (Energy, Mines and Resources Canada 1993a). Leaks from coke oven doors are being addressed by industry investment in appropriate equipment and an extensive maintenance program.

Steel production technology is changing rapidly in Canada, with emphasis on pollution prevention. Improvements include "zero discharge" processes for some rolling, finishing, plating, and galvanizing operations. Alternative technologies that would eliminate the need for blast furnaces and coke ovens altogether, resulting in little or no releases of organics, are not likely to be available to integrated Canadian producers for 10–20 years (Energy, Mines and Resources Canada 1993a). In the interim, other technologies, such as pulverized coal, fuel oil, and natural gas injection in blast furnace production, are reducing the coke requirement for iron-making (R. DiCarlo and K. Mah, Environmental Protection Service, Environment Canada, personal communication).

Base metal smelting takes place at high temperatures in various types of smelting furnaces. The furnaces emit air pollutants, primarily sulphur dioxide, particulate matter, nitrogen oxides, and heavy metals; some may emit volatile organic compounds (VOCs). The type and degree of environmental impact depend on the type of metal produced and the sulphur content in the concentrate, as well as on the age and size of the smelter. A significant reduction in air pollution has been achieved by changing some metal-producing processes from pyrometallurgy (high temperatures) to primarily hydrometallurgy (wet processes). Improved emission control technology has also made a large contribution to reducing airborne pollution from smelters (Mining Association of Canada 1995).

Sulphur dioxide

The largest emission source of sulphur dioxide in Canada is smelting of metal concentrates, which contributed 50% of total eastern Canadian sulphur dioxide in 1994. Power generation and other sources contributed 20% and 30%, respectively (Environment Canada 1996a).

There are 10 Canadian primary base metal smelters, producing nickel, copper, lead, and zinc. Their metallurgical processes result in the production of large amounts of sulphur dioxide during the smelting process. Most of these smelters have implemented sulphur dioxide controls that reduce the amount of sulphur

Box 11.11
Land use and land access issues

Mineral reserves are widely dispersed, and exploration for those minerals requires large areas of land. Furthermore, the mining operation itself is at the hub of an infrastructure of access roads, tailings ponds, power lines, water use, and other aspects of mining. Without proper management, the impacts of exploration and mining on the land resource can be substantial. The mining industry now faces competition and opposition to land access from conservation groups, Aboriginal land claims, and other interests concerned about the cumulative impacts of mineral exploration and development and the long-term impacts of abandoned or unreclaimed mine sites. Also of concern are the potential negative impacts downstream from mining operations and the impacts on adjacent land users and wildlife from roads and unreclaimed sites.

Mining in the past, in a world that had not encountered sustainable development, was relatively unrestricted. This has left a legacy of negative environmental impacts from mining that are spurring opposition to any exploration that might eventually lead to mine development. The mining industry perceives that environmental groups and Aboriginal peoples are the two sectors that will potentially have the greatest impact on the access of land for mining, owing to pending settlement of Aboriginal land claims and completion of Canada's protected area networks (Whitehorse Mining Initiative 1994a). The mining industry, for the most part, has taken significant steps to ensure that mining practices, from exploration through to reclamation, are conducted in environmentally responsible ways, through improved awareness, improved technology, and better management (Whitehorse Mining Initiative 1994a).

Canada has yet to systematically collect accurate data on the nature and extent of land used by the mining industry (Government of Canada 1991). The most recent national assessment available was published by Environment Canada in 1982. At that time, an estimated 279 477 ha, or less than 0.03% of Canada's land area, was disturbed, used, or alienated by mining activities (Marshall 1982). Six percent of Canada's land area is closed to mining; about four-fifths of this is in protected areas such as parks. This will change, as each of Canada's 13 senior governments has committed to complete its own protected area network, with the goal of capturing at least 12% of Canada's natural regions and critical wildlife habitat in protected areas (Whitehorse Mining Initiative 1994a).

Natural Resources Canada, in conjunction with the provinces and nongovernmental organizations, is promoting the development of a national land use information network to integrate data on land use and mineral potential across Canada for future decision-making on mineral development. This is one of many actions originating from the Whitehorse Mining Initiative (see Box 11.15) and its Land Access Issue Group.

Developing a sustainable mining industry in Canada depends on resolving land use issues. Environmental, social, and economic goals and commitments must be integrated into mining at all phases, and land use will be a critical factor in this process (Whitehorse Mining Initiative 1994a).

dioxide that enters the atmosphere (MacLatchy 1994). Figure 11.31 shows that quantities of sulphur dioxide released from eastern smelters and refineries have been substantially reduced since 1980, as a result of the Eastern Canada Acid Rain Control Program.

Reductions have been achieved by a combination of installing new equipment to capture sulphur dioxide for the manufacture of sulphuric acid, upgrading existing equipment for sulphur dioxide recovery, and metallurgical changes to the milling and smelting processes (E. Gardiner, Mining Association of Canada, personal communication). New smelting technologies and processes have resulted in major reductions in sulphur dioxide releases. Figure 11.32 shows the generally decreasing trend in emissions of sulphur dioxide per kilotonne of metal produced at selected smelters in eastern Canada.

The industry is addressing environmental and social concerns related to mining. In 1987, the governments of Canada and Quebec and Noranda Inc. cooperated

Box 11.12
Case study: the Tatshenshini/Alsek area

The Tatshenshini/Alsek area in northwestern British Columbia is a remote wilderness without permanent settlements. The only human activities in the region are hiking, rafting, wilderness science, and mining. In July 1992, the B.C. government asked the Commission on Resources and Environment (CORE) in British Columbia to review and report on the land use of the Tatshenshini/Alsek area. The request was prompted by a proposal for a major copper mine development at Windy Craggy Mountain and the potential this posed for a major confrontation between proponents of the mine and conservationists. Consensus negotiations were unlikely to resolve the land use issues, because the most directly involved parties held completely contrary views regarding the appropriate use of the area.

The proponents of the mine, including Geddes Resources Ltd., the mining industry, and mining employment sectors, believed that mining in the area would be a safe use of the land that would be compatible with wilderness values. Conservation interests believed that resource extraction would harm what they perceived as extraordinary wilderness values. Furthermore, the region is near the international border, with implications for the U.S. and Canadian federal governments and for the Yukon, B.C., and Alaska governments in terms of downstream effects and mining and water regulations. Following completion of the CORE process, which included public information forums in many communities in British Columbia, the CORE report presented several options to the provincial government: the wilderness option, the mining option, and the delayed decision option (Commission on Resources and Environment 1993).

In June 1993, the B.C. government announced that the Tatshenshini/Alsek area would be made into a protected area. In December 1994, the area was designated as a World Heritage Site.

Table 11.16
Estimates of all mine wastes as well as acid-producing and potentially acid-producing mine wastes in Canada as of 1994

	All wastes[a]			Acid-producing and potentially acid-producing wastes[b]		
	Tailings		Waste rock	Tailings		Waste rock
Province/territory	t, millions	ha	t, millions	t, millions	ha	t, millions
Newfoundland	608	4 030	604	29.5	170	0.5
New Brunswick	78	614	27	76.5	564	25.7
Nova Scotia	19	190	47	11.3	90	35.9
Quebec	1 884	8 405	2 704	254.0	2 390	70.0
Ontario	1 677	11 882	128	984.0	6 481	80.1
Manitoba	209	2 400	102	200.0	1 780	68.8
Saskatchewan	391	2 103	54	66.4	273	19.9
British Columbia	1 732	10 571	2 571	192.0	571	421.0
Yukon/Northwest Territories	213	1 243	27	64.0	243	17.0
Canada	6 811	41 438	6 264	1 877.7	12 562	738.9

Note: Where estimates of either hectares or tonnes were unavailable, the assumption used was that there were 150 000 t of tailings per hectare and 400 000 t of waste rock per hectare.

[a] Excludes estimates of wastes from surface coal mining in Saskatchewan and Alberta and wastes from oil sands mining in Alberta.
[b] Estimates include wastes at mine sites that have been fully rehabilitated or at sites where wastes have been deposited under water cover.

Source: Feasby and Tremblay (1995).

financially to create a project at Noranda's Horne division to reduce the 1980 emission level of sulphur dioxide by 50% by 1990. This project cost in the order of $83.2 million and permitted a reduction of sulphur dioxide emissions from 550 kt in 1980, or 1 507 t/day, to 156 kt in 1995, or 427 t/day. Additional investments are predicted to reduce sulphur dioxide emissions to around 40 kt/year to meet the new Quebec standards that will be in place by 2002 (G. Houle, Direction des politiques du secteur industriel, Ministère de l'Environnement et de la Faune du Québec, personal communication).

Another notable example of industry response was the $600 million modernization of Inco's Copper Cliff smelter near Sudbury, Ontario, over a five-year period from 1988 to 1993. This modernization involved the rejection of iron sulphide in the milling process. State-of-the-art smelting furnaces using oxygen instead of air and new sulphuric acid and liquid sulphur dioxide plants have resulted in a major reduction in sulphur dioxide releases. The operation's sulphur containment has increased from 70% to 90%, and Inco is marketing the recovered sulphur dioxide as sulphuric acid. The investment in improved technology has benefited the environment and also substantially reduced the company's annual energy costs.

Also in Sudbury, Falconbridge Ltd. has reduced its sulphur dioxide emissions to the point where it can operate its smelter at 100% capacity, yet remain below the provincial sulphur dioxide limits. In 1993, Hudson Bay Mining and Smelting at Flin Flon, Manitoba, began operation of its oxygen pressure leach zinc plant. This technology reduced sulphur dioxide emissions from the zinc plant by recovering sulphur as a solid waste. In Trail, British Columbia, Cominco Ltd. is proceeding with a new lead smelter and slag plant that will reduce lead emissions by some 70–80% (McLellan 1995).

Internationally, the federal government, with provincial support, is active with the United Nations Economic Commission for Europe (UN-ECE) on atmospheric issues. In June 1994, Canada signed the Second UN-ECE Sulphur Dioxide Protocol, which commits Canada to cap sulphur dioxide emissions and to work towards critical loads (the level of acidic deposition that causes insignificant environmental harm). Canada is participating in UN-ECE negotiations on a second nitrogen oxide protocol and will take part in negotiations on potential protocols for persistent organic pollutants and for heavy metals.

Bilaterally, the Canada–United States Air Quality Agreement, signed in 1991, committed Canada to cap national sulphur dioxide emissions at 3.2 million tonnes annually (from 4.6 million tonnes) by the year 2000 and to cap eastern Canadian sulphur dioxide emissions at 2.3 million tonnes annually between 1994 and 2000. By 1994, industry had exceeded the tar-

Box 11.13
Promising techniques for preventing and controlling acidic drainage

Several promising techniques for acidic drainage are being developed under the Mine Environment Neutral Drainage (MEND) program. Acid generation may be prevented or reduced by submerging sulphide materials in shallow or deep water. This creates an anaerobic environment that discourages oxidation and bacterial action. Tailings disposal in the deep water of northern lakes, such as at the Polaris Mine, has produced excellent results: sulphides appear to remain stable, and dissolved metal concentrations are low (Ripley et al. 1996).

Unfortunately, subaqueous disposal is not an option for more than half of the existing tailings sites in Canada, because of the following factors: the lack of suitable water bodies to flood the wastes, thermal turnovers in lakes, the permeability of the underlying ground, the presence of oxidation products in the tailings, or the location of the waste material at the surface — waste rock is impractical to flood unless the rock is returned as backfill in underground mines or to mined-out open pits (Feasby and Tremblay 1995; Mine Environment Neutral Drainage Program 1995).

Layered earth covers are being investigated. They are effective but costly to instal in many areas of the country (Feasby and Tremblay 1995; Mine Environment Neutral Drainage Program 1995). Passive treatment methods, such as engineered wetlands, have been investigated for application to metal mine acidic drainage in Canada. In this process, metals are absorbed by plants, such as cattails. This technique has been used successfully in Elliot Lake. Adding lime to neutralize the acid is another technique that is being used for treatment of acidic drainage (Ripley et al. 1996).

Long-term methods for the management of tailings and waste rock are being researched. Flooding impoundments for uranium tailings look promising. The East Sullivan Mine in Quebec is testing an organic cover made of 2 m of softwood and hardwood bark overplanted with grasses. Along the same lines, Falconbridge is experimenting with compost, which creates anaerobic conditions and effectively halts oxidation, "thus reversing acid drainage processes and possibly even reducing trace metals" (Ripley et al. 1996). Municipal sewage is one form of compost being tested at Falconbridge. Another engineered cover being tested for durability for large-scale applications on acid-generating waste rock piles is the use of a cementitious cover. The prohibitive cost of aggregate for the cementitious covers has steered the MEND program away from further research into these areas (Ripley et al. 1996).

What has been confirmed in the MEND program is that prevention is the best solution for acidic drainage (Feasby and Tremblay 1995). The best preventive measure is to design an impoundment for subaqueous disposal of tailings, taking into consideration water sources, climate, and geology of each site and factoring in the chemical and physical properties of the waste material (Ripley et al. 1996).

get, reducing emissions to 1.7 million tonnes. The United States also committed to reducing sulphur dioxide emissions by 40% from 1980 levels. Despite these successes, acid rain will continue to be an issue in the next century. As a result, Canada is considering further sulphur dioxide emission reductions (Government of Canada 1996).

Box 11.14
Environmental aspects of primary iron and steel production

The basic raw materials for iron and steel production are iron ore, mainly in the form of pellets, scrap, coal, and fluxes such as limestone, calcined lime, and dolomite. Iron is made by two processes: blast furnace and direct reduction. In the blast furnace process, iron ore is combined with coke (made from coking coal) and limestone to produce molten iron for steelmaking in the basic oxygen furnace in integrated steel mills. In direct reduction, iron ore pellets are converted into sponge or reduced pellets. An electric arc furnace is used in nonintegrated or "mini" steel mills to produce steel primarily from scrap or direct reduced iron. In 1994, 58% of the steel produced in Canada was from basic oxygen furnaces and 42% from electric arc furnaces. About 53% of the steel produced in Canada in 1994 came from recycled iron and steel scrap (Smith 1995).

Approximately 65% of the steel produced in Canada comes from Ontario's four integrated facilities. About 70% of the estimated 1.3 million cubic metres per day of process effluent and the 1.6 million cubic metres per day of cooling water discharged into Ontario waterways is from plants in Sault Ste. Marie and Hamilton (Ontario Ministry of Environment and Energy 1994).

Environmental concerns related to iron and steel operations relate primarily to the discharge of toxic emissions from coke ovens and furnaces and to waterborne acidic wastes or sludges. Table 11.B2 shows releases from both integrated and non-integrated steel mills.

Table 11.B2
Preliminary estimates of 1992 releases from the Canadian iron and steel industry[a]

Type of contaminant released	Releases (t)			
	Air	Water	Solid waste	Total
Organics[b]	1 891	1 276	16	3 183
Metals[c]	387	64	23 792	24 242
Acids[d]	38	N/A	N/A	38
Solvents[e]	183	0	0	183
NOx	24 815	0	0	24 815
CO	757 057	0	0	757 057
CO_2	6 809 397	0	0	6 809 397
SO_2	48 885	0	0	48 885
Dust	18 427	0	0	18 427

Note: N/A = not available.

[a] Solid wastes such as slag, mill scale, dust, etc. are considered as releases in this table. Many slags, mill scales, and dusts are subsequently sold and used in other industries or reprocessed for use in ironmaking and steelmaking. Consequently, these are overestimates of net releases to the environment.
[b] Includes ammonia, benzene, cyanide, phenols, and polycyclic aromatic hydrocarbons (PAHs).
[c] Includes chromium, lead, nickel, and zinc.
[d] Includes hydrochloric and sulphuric acid.
[e] Includes dichloromethane, trichloroethane, tetrachloroethylene, and trichloroethylene.

Source: Data from R. DiCarlo, Steel Section, Mining, Minerals and Metallurgical Division, Environmental Protection Service, Environment Canada.

The economic impact of controlling airborne pollutants in the metals industry has been generally positive. The introduction of technologies that reduce sulphur dioxide emissions has generally improved productivity and reduced operating costs, while controlling airborne pollutants.

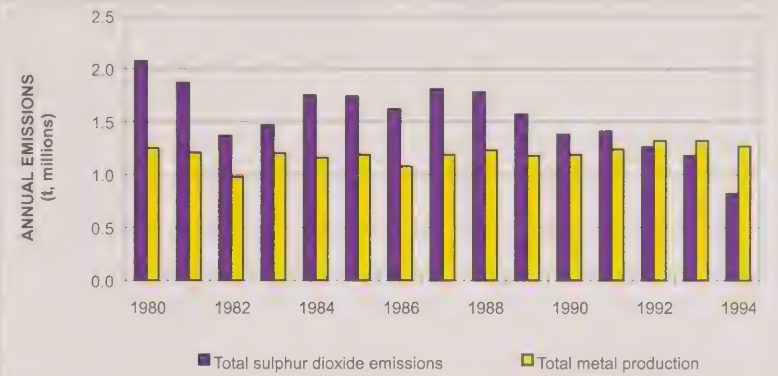
Heavy metal airborne particulates
Conventional base metal smelting and refining processes emit metal compounds as particulates into the atmosphere. Smelter facilities require design changes to enable capturing and recycling or alternative treatment of particulates.

The process of recovering sulphur dioxide as sulphuric acid has helped reduce heavy metal emissions to the environment. Waste gases must be scrubbed and cooled to remove particulates containing most of the heavy metals before sulphur dioxide can be recovered in the acid plant. Heavy metals that occur in a gaseous state, such as most mercury, some arsenic oxide, and lesser amounts of other metals, are usually removed prior to acid production.

Although there is almost 100% removal of metals contained in the high-strength sulphur dioxide gases prior to their being processed by an acid plant, metal losses may still occur from fugitive emissions and from low-strength sulphur dioxide waste gases that cannot be processed by the acid plant.

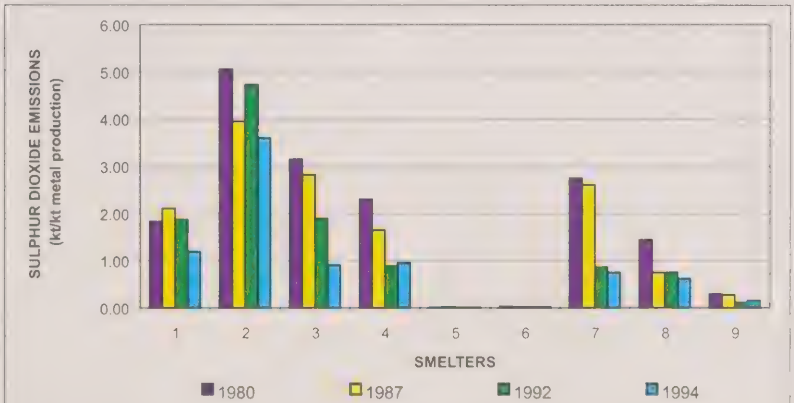
The major smelters in Canada report emission reductions of 67% for arsenic, 30% for cadmium, 40% for lead, 59% for mercury, and 54% for nickel between 1988 and 1993 (Mining Association of Canada 1995). Other metals will be reduced by similar amounts. Figure 11.33 shows the emissions of substances listed under the Accelerated Reduction/Elimination of Toxics (ARET) program by mining industry ARET participants. ARET is explained later in this component, under the section "Cooperative efforts to address environmental concerns."

Figure 11.31
Sulphur dioxide emissions and base metal production from eastern Canadian base metal smelters, 1980–1994



Source: MacLatchy (1994, and personal communication).

Figure 11.32
Sulphur dioxide emissions per kilotonne of metal production at selected smelters in eastern Canada, 1980, 1987, 1992, and 1994[a]



Smelter/location

1. Hudson Bay Mining and Smelting, Flin Flon, Manitoba[b]
2. Inco Ltd., Thompson, Manitoba
3. Inco Ltd., Sudbury, Ontario
4. Falconbridge Ltd., Sudbury, Ontario
5. Falconbridge Ltd., Kidd Creek Division, Timmins, Ontario[c]
6. Canadian Electrolytic Zinc (Noranda), Valleyfield, Quebec[d]
7. Noranda Minerals Inc., Rouyn-Noranda, Quebec
8. Noranda Minerals Inc., Murdochville, Quebec
9. Brunswick Mining and Smelting Ltd., Belledune, New Brunswick

[a] In this figure, smelting refers to pyrometallurgical processes used in the production of metals from sulphide concentrates, including the roasting of zinc from concentrates.

[b] The increase in SO_2 per kilotonne of metal production from 1980 to 1987 is attributable to variability in the sulphur content of concentrates handled at this custom smelter.

[c] The values for 1980, 1987, 1992, and 1994 are 0.01, 0.02, 0.01, 0.01.

[d] The values for 1980, 1987, 1992, and 1994 are 0.03, 0.02, 0.02, 0.02.

Source: MacLatchy (1994, and personal communication).

Post-operational waste management

There are over 6 000 active, abandoned (i.e., no longer operating, owners known), and orphaned (i.e., no longer operating, owners unknown) tailings sites in Canada. However, there is no comprehensive inventory with an assessment of the risk that these sites pose. This gap prompted the House of Commons Standing Committee on Natural Resources to recommend that the federal government (Natural Resources Canada), in cooperation with the provinces, territories, and industry, establish a national database on active and abandoned mining sites and the reclamation work needed at those sites (Standing Committee on Natural Resources 1994a). Work is under way to address these deficiencies.

The environmental hazards posed by abandoned mine sites are potentially serious, even if a mine site does not contain any harmful materials. Acidic drainage, and the resulting contamination by metals, is the most common problem. In former uranium mining areas, the National Uranium Tailings Program concluded that radioactivity from tailings is not likely to expose humans to any undue risks and that other environmental contaminants in tailings, such as metals from acidic drainage, were a greater concern (Government of Canada 1991) (see the "Energy use" component of this chapter for more detail on radioactive wastes). The land use potential of a site remains permanently altered by abandoned rock pits, gravel quarries, and other relatively harmless mining operations (Government of Canada 1991). Mining shafts, dredges, oil barrels, fuel, and other equipment have also been left throughout the country by former mining operations and may pose immediate safety and environmental risks.

Liability for past, present, and future mines is a key issue in mining today. Under current legislation, a mining company is responsible for mine closure and reclamation and for costs resulting from future environmental impacts. Mining companies may be required to post bonds even before mining begins, to ensure funding for an environmentally acceptable closeout and long-term monitoring of efflu-

ents and their effects on receiving environments. However, a legacy of abandoned mine sites remains throughout Canada, dating back to times when environmental considerations were minimal. If a mine operator cannot be identified, the mine title reverts to the Crown, and the public, through the provincial and federal governments, assumes the responsibility and costs for site rehabilitation (Government of Canada 1991). This issue is of particular concern to provincial governments, as most mines fall within provincial jurisdiction (Natural Resources Canada 1995d).

An estimated 7 billion tonnes of metal mine and industrial mineral tailings cover about 41 000 ha of the Canadian landscape. In addition, approximately 6 billion tonnes of waste rock are deposited at mine sites (see Table 11.16). The rehabilitation costs for non-acid-generating sites are estimated to be over $1 billion (Feasby and Jones 1994). The cost of dealing with sites where acidic drainage occurs is estimated to be $2–5 billion.

Current site rehabilitation standards are provincially based, focusing on effective covers and long-term stability of dams, waste rock piles, and other structures and, if necessary, on the treatment of contaminated seepages and runoff. Increasing attention has been directed to the establishment of sustainable ecosystems as a long-term goal. The standards and requirements faced by the operator vary with location, commodity, and jurisdiction. Hence, the requirements facing metal mine operators are very different from those facing producers of aggregates, industrial minerals, potash, coal, or oil sands.

Cooperative efforts to address environmental concerns

There are significant gaps in knowledge about the environmental effects of mining. Not enough is known about the toxicity and fate of metals and the effects of industrial emissions and effluents on various components of ecosystems. Moreover, much remains to be learned about the design of techniques to address the related problems. In recent years, various multistakeholder cooperative programs have been launched to reduce the environmental impacts of mining. The Whitehorse Mining Initiative (WMI) was the first consultative process involving industry, federal and provincial/territorial governments, environmental and Aboriginal communities, labour, and educators (McLellan 1995). This accord, signed in September 1994, identified the environment as one of the four areas of concern for the industry (see Box 11.15).

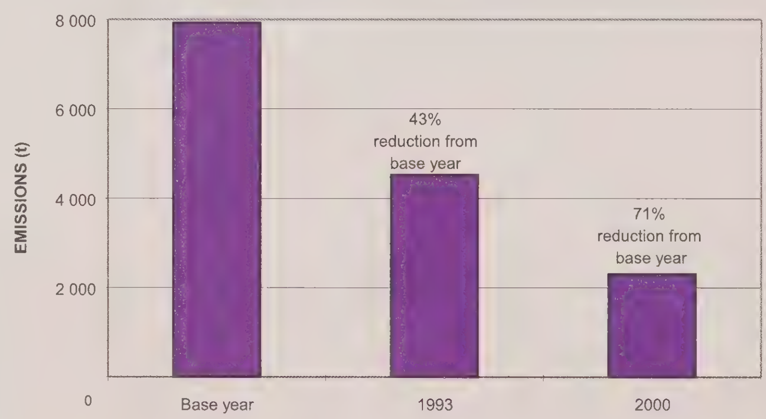
Four other multistakeholder cooperative programs are the Assessment of the Aquatic Effects of Mining in Canada (AQUAMIN) process, the Aquatic Effects Technology Evaluation (AETE) program, the MEND program, and the ARET program.

Under AQUAMIN, several provinces, industry, the Canadian Environmental Network, Aboriginal groups, and several federal government agencies are participating in a review of the effects of metal mining on the aquatic environment. The objectives of the review are to identify the impacts of mine effluents on the aquatic environment, to evaluate the adequacy of the MMLER and recommend amendments, and to make recommendations on design of a national environmental effects monitoring program. This process is to be completed in 1996 (Canadian Institute of Mining, Metallurgy and Petroleum 1995; B. Blakeman, Environmental Protection Service, Environment Canada, personal communication).

AETE is a four-year program designed to evaluate existing technologies for assessing the impacts of mine effluents on the aquatic environment. The evaluations include reviews of available technical information and field case studies. The results will complement AQUAMIN by providing a common scientific basis for meeting the mining industry's environmental effects monitoring needs in a cost-effective manner. The program is to be completed in 1998 (D. Campbell, CANMET, Natural Resources Canada, personal communication).

MEND is a voluntary cooperative technology development program financed and administered by a partnership of 21 mining companies, 5 federal government agencies, and 8 provincial governments. Depending on the treatment and the con-

Figure 11.33
Emissions of major ARET-listed substances by mining industry ARET participants



Note: ARET = Accelerated Reduction/Elimination of Toxics, a multistakeholder program aimed at voluntarily reducing emissions of contaminants in manufacturing and mining industries.

Source: Mining Association of Canada (1995).

trol technology used, the rehabilitation and maintenance costs or liabilities for acid-producing mine waste in Canada are estimated to range from $2 billion to $5 billion. In response to these projected high costs and the need for less expensive technologies for preventing and managing acidic drainage, the Canadian mining industry and governments joined forces in 1988 to form the MEND program. The $18.5-million research program was initiated in 1989, was redefined and refocused in 1992, and is scheduled for completion at the end of 1997.

The two major objectives of MEND are (1) to provide a comprehensive, scientific, technical, and economic basis for the mining industry and government agencies to predict with confidence the long-term management requirements for reactive tailings and waste rock; and (2) to establish techniques that will enable the operation and closure of acid-generating tailings and waste rock disposal areas in a predictable, affordable, timely, and environmentally acceptable manner. The research and development component of MEND concentrates on four main areas: prediction, prevention and control, treatment, and monitoring. A fifth component, technology transfer, focuses on communicating the technology developed in the MEND program to potential users (Mine Environment Neutral Drainage Program Secretariat, undated; Feasby and Jones 1994; Mining Association of Canada 1995).

ARET is a multistakeholder initiative aimed at mining and manufacturing. It was established to determine whether voluntary approaches can achieve environmental goals more quickly and more cost-effectively than regulatory or legislated approaches. In 1994, the ARET committee, which includes representatives from industry, health and academic associations, and government, challenged members to develop action plans for reducing and eliminating releases of 12 substances to the environment: arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, silver, zinc, cyanide, and hydrogen sulphide.

As part of the ARET program, 13 mining companies representing 83% of Canadian base metal production have submitted reduction plans for the 12 ARET-listed substances. These companies reduced releases by 43% between the base year (1988 or later) and 1993 and have committed to total reductions of 71% of the annual releases of these substances combined, from 7 927 t in the base year to 2 307 t in the year 2000 (Canadian Institute of Mining, Metallurgy and Petroleum 1995; Mining Association of Canada 1995).

The major national mining organizations, including the Mining Association of Canada, the Prospectors and Developers Association of Canada, and the Canadian Institute of Mining, Metallurgy and Petroleum, have adopted environmental policies, and a number of Canadian mining companies now publish annual environment reports (McLellan 1995). The Canadian mining industry has also undertaken several initiatives to define and achieve sustainability for the mining sector. Canadian industry currently has ongoing input into the ISO (International Organization for Standardization) 14000 discussions on mining. Canadian mining companies also played an important role in establishing the International Council on Metals and the Environment (ICME). This international organization, based in Ottawa and composed of major nonferrous and precious metal producers from five continents, has established an Environmental Charter for members, in order to foster environmentally sustainable economic development (ICME, undated).

Conclusion

The mining industry provides many of the essential raw materials used by society. In Canada, it contributes significantly to the economic well-being of Canadians. However, the economic life of any given mine is

Box 11.15
Whitehorse Mining Initiative

As the mining industry entered the 1990s, it recognized that "it needed support, assistance and advice within a non-adversarial framework to create a new strategic vision and to find solutions appropriate to the new economic and environmental realities. As a result, at the suggestion of the Mining Association of Canada (MAC), the Whitehorse Mining Initiative (WMI) was conceived in the fall of 1992. The intent of this undertaking was to move towards an economically and environmentally sustainable industry that is fully supported by political and community consensus" (Pilsworth and Kokkinos 1995).

WMI brought together stakeholders in the mining process in Canada to develop a common vision for mining in this country. Representatives of five sectors — mining industry, senior governments, labour unions, Aboriginal peoples, and the environmental community — participated in this process to arrive at an accord in 1994. The WMI vision is "of a socially, economically and environmentally sustainable, and prosperous mining industry, underpinned by political and community consensus" (Whitehorse Mining Initiative 1994b). In addition to the vision, the accord contains 16 principles, 70 goals, and a statement of commitment to follow-up action.

The principles and goals are in six main groups:

- *addressing business needs;*
- *maintaining a healthy environment;*
- *resolving land use issues;*
- *ensuring the welfare of workers and communities;*
- *meeting Aboriginal concerns; and*
- *improving decisions.*

This accord is a consensus report of all stakeholder groups. Whether or not the vision of the WMI will be realized will depend on the commitment of the stakeholders to achieving the agreed-to principles (Miller 1995).

limited: minerals and metals are found in deposits, most of which were formed millions of years ago and are finite. The environmental legacy left by mining may be in the form of acid-generating wastes, heavy metals, and many other potential problems. However, a mining company today is required to pay for the reclamation of a mine site if it has the legal responsibility for that mine reclamation.

With these major challenges, the mining industry stands at the leading edge of implementing the concept of sustainability. The issue of mine decommissioning, in particular, reaches to the very core of the technical, legal, financial, and social dimensions of sustainability. In some cases, geochemical conditions at decommissioned properties will cause the release of contaminants thousands of years into the future. Current analytical techniques are not sufficiently advanced to meet the challenge of distributing these costs across the many implicated generations, and yet the mining companies must make decisions about their activities today if they are to stay in business. The transition to sustainability will entail collaboration, communication, and flexibility to maintain the industry's competitive position internationally, while accounting for the full human and environmental costs of mining.

The increasing attention being paid to reducing the environmental stress imposed by mining is, almost without exception, resulting in significant economic benefits. Reductions have been made in the use of water, processing chemicals, and energy, leading to significant cost savings. Without exception, these reductions are linked to improvements in process efficiencies, which themselves generate savings. In addition, new export opportunities have emerged for equipment, processing, engineering, and management systems.

The trend towards cooperative problem-solving in the sector, as evidenced by multistakeholder programs such as the WMI, ARET, AQUAMIN, and AETE, suggests that the parties recognize that it is in the best interests of all concerned to work together to develop and implement sound environmental policies and practices to ensure sustainable development. The concept of sustainable development is motivated by an overarching goal of improving or maintaining human and ecosystem well-being together. It implies a bridging of environmental, social, cultural, and economic factors in day-to-day decision-making. The mining industry is now exploring practical implementation of this concept, a challenge that will continue well into the next century.

ENERGY USE

Introduction

Life on Earth would not be possible without energy. Direct energy from the sun drives most of the Earth's natural cycles and sustains vegetation and animal life. These, in turn, support human life. In modern societies, energy is also essential for everything from cooking, heating, and lighting to transportation, computers, leisure, and industrial processes.

Energy resources play a major role in the Canadian economy. In 1994, nearly 8% of Canada's GDP (excluding gasoline service stations, wholesale petroleum products, and propane), 17% of gross investment, and 10% of gross export income were attributable to energy production (Statistics Canada and Natural Resources Canada 1995).

Some of the impacts that energy production, transportation, and other end uses have on Canada's environment are examined in this component. Recent trends in energy impacts on the environment are discussed, as well as the challenges that must be faced to alleviate present environmental damages and avoid future harm.

Energy demand and supply

Intensity of consumption

Canadians use more energy per person than people in most other countries (Fig. 11.34). In terms of the energy efficiency of our economy, Canada fares somewhat better, but it is still one of the most energy-intensive countries in the world.

There are several reasons why Canada is an energy-intensive country: a cold climate, an energy-intensive industrial base (e.g., pulp and paper, iron and steel production, mining), a large land area and low population density, which create a high demand for transportation services, and relatively low energy prices.

Canadians also enjoy a high standard of living compared with much of the rest of the world. We have numerous appliances and energy-consuming products. However, our heavy reliance on private cars and single-family homes and the absence in urban areas of district heating and cogeneration systems, common in Europe, contribute even more to higher Canadian energy use (Torrie 1993).

Nevertheless, Canadians cannot take the country's energy wealth for granted. Shortages in light crude oil, from which gasoline is manufactured, are expected in the next few decades (National Energy Board 1994a). More importantly, energy production and use impose costs in terms of environmental stress, with multiple and varying effects on different regions of Canada. Canadians may wish to reduce their consumption of fossil fuels as concerns over greenhouse gas emissions increase.

Evolution of energy demand

Between 1973 and 1985, the energy intensity of the Canadian economy declined markedly (Fig. 11.35), largely in response to the oil price shocks of 1973 and 1979. About 25% less energy was needed in 1985 to produce one unit of economic output than was needed in 1973. This is in sharp contrast to the experience over the period 1958–1973, when the energy needed to produce one unit of economic output rose by 14%. GDP-related energy intensity (total primary energy supply per unit of GDP; for a definition of primary energy, see Box 11.16) fell 20% between 1970 and 1992 and 15% between 1980 and 1992 (OECD 1995).

During the past two and a half decades, the demand for different types of energy has changed as well. Oil, which provided near-

ly half of Canada's energy needs in 1970, now accounts for less than a third of national energy consumption (Fig. 11.36).

In 1994, total Canadian end-use energy (secondary energy minus petroleum feedstocks) was 6 700 PJ (Statistics Canada 1994d). Industry accounted for the largest share (31%), whereas transportation accounted for 30%, residential sector 19%, commercial sector 17%, and agriculture 3% (see Chapter 2, Fig. 2.3).

As in other OECD nations, the period from 1973 until the mid-1980s was a time when energy security, and especially security of oil supply, was a major public policy objective in Canada.

Between 1971 and 1987, the domestic demand for fuels and electricity per 1981 dollar of GDP dropped 30%, marking a significant departure from the synchronicity of secondary energy use and GDP growth that had characterized the pre-1973 period (Fig. 11.37). In fact, the improvement in the energy productivity of the Canadian economy made a larger contribution to security of supply over this period than all new sources of oil, gas, and electricity combined.

An analysis prepared for the federal government (Marbek Resource Consultants et al. 1989) offers some insight into how and why energy use and demand have changed. According to this study, 65% of the decline in energy demand between 1971 and 1988 was due to improvements in energy efficiency, and 35% was due to structural change in the economy, particularly in the industrial sector, where the mix of industries shifted towards those that required less energy (internal database, Torrie Smith Associates, Ottawa).

The biggest improvements in energy efficiency have been in the residential and transportation sector. The residential improvements were largely motivated in the late 1970s by new building code standards for new housing and government incentive programs for retrofitting older houses. In the transportation sector, the adoption by auto manufacturers of federal fuel efficiency targets established in the mid-1970s had a similar effect (Marbek Resource Consultants et al. 1989).

The study offers a number of useful lessons about how to improve energy efficiency. The most effective tool, it found, was the application of energy efficiency standards: efficiency improvements were greatest where standards were applied and lowest where they were not. Price alone was not a strong motivation for improving efficiency. In the industrial sector, for example, although energy prices increased by 427% over the study period, the net improvement in efficiency was only about 7%.

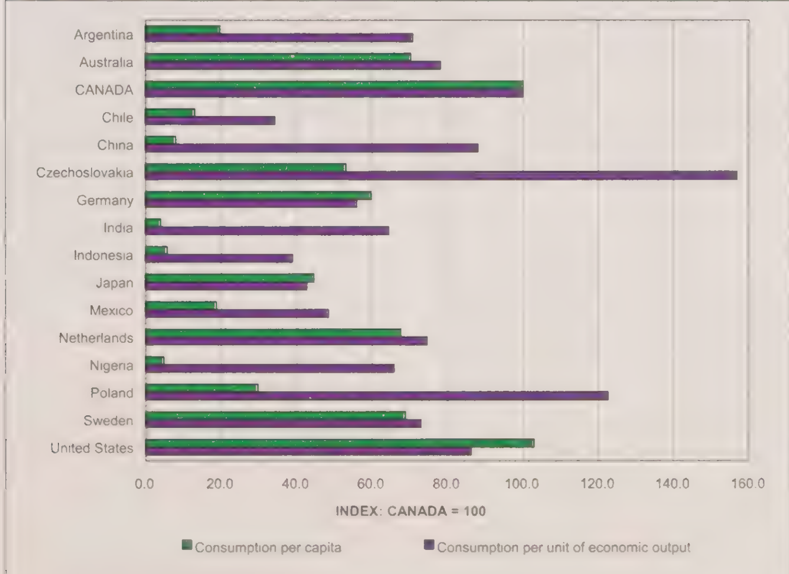
The largest gains occurred when there was a combination of different interventions carried out against a backdrop of public support and rising prices. Efficiency standards worked best when complemented by other techniques, such as information dissemination and the provision of financial incentives. Even in the absence of renewed price pressure, effective information on the benefits of alternative technologies and consumption patterns and their benefits (including their environmental benefits) could be a powerful tool for increasing energy efficiency.

Concerns about price and security of supply no longer offer the powerful incentive to conserve energy that they did in the 1970s and early 1980s (Kowalski 1989, 1992). Indeed, after remaining relatively stable from 1974 to 1984, total energy consumption in Canada has been rising since 1985, while energy intensity (energy consumption per unit of economic output) decreased only 3% between 1985 and 1992.

Energy outlook

Natural Resources Canada and the National Energy Board have both recently published energy projections for Canada (National Energy Board 1994a, 1994b, 1994c; Natural Resources Canada 1993, 1994c). These are shown in Table 11.17. Although the two sets of projections differ with respect to some of the underlying assumptions and projected values, the overall picture that emerges is broadly the same.

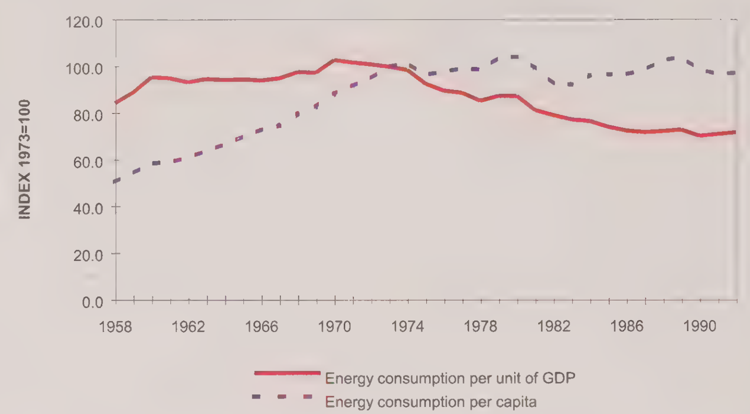
Figure 11.34
Energy intensity, by selected country, 1991



Source: World Resources Institute (1994)

Projections such as these are useful benchmarks for highlighting how Canada's energy future and the environmental effects associated with it are likely to evolve *if* economic development proceeds as currently envisaged, *if* behaviour patterns and lifestyles are unaltered, and *if* government policies at all levels remain unchanged. With the growth rate for petroleum demand spiking sharply upwards while that for renewables increases only moderately, environmental stresses from energy use are almost certain to increase — regionally, nationally, and internationally. However, such projections do not represent an inevitable future. By adopting appropriate policies, technologies, and attitudes, Canadians and their governments can shape a more environmentally benign pattern of energy production and use.

Figure 11.35
Energy consumption intensity trends, 1958–1992



Source: Statistics Canada (1994d); State of the Environment Directorate, Environment Canada.

> **Box 11.16**
> **Primary, secondary, and end-use energy**
>
> ***Primary energy*** *represents the total energy available for all uses, including energy actually used by the final consumer as well as energy used to make other forms of energy (e.g., coal used to make electricity), energy used by suppliers to bring energy to the market (e.g., fuel for pipeline compressors), and imported energy minus exported energy.*
>
> ***Secondary energy*** *is the energy available for use by the residential, commercial, and industrial sectors and for transformation into other forms of energy. It also includes hydrocarbons, like oil, that are used for nonenergy purposes, such as petrochemical feedstocks. Secondary energy is less than primary energy because of losses in conversion and distribution.*
>
> ***End-use energy*** *is similar to secondary energy but does not include nonenergy uses or uses and losses by the energy industry itself.*

Environmental trends and issues

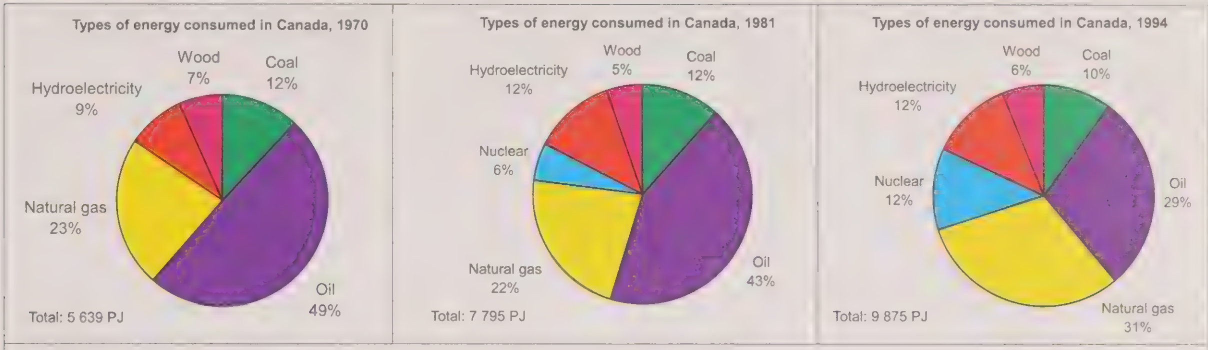
Many aspects of energy production and use, from exploration to final consumption, affect the environment as well as human health. Some effects are temporary and easily reversed, but others are more long lasting and, in some cases, irreversible. Although the ecological consequences of energy use are usually local and regional, they can also be global in nature.

Fossil fuels (petroleum, natural gas, and coal), which currently supply about 70% of Canadian energy requirements, are major contributors to three of the more important air pollution problems of today: climate change (a global concern), acidic deposition (a regional and continental problem), and urban smog (a local and regional problem). Although significant progress has been made in reducing acid rain, progress on the other two issues has been more elusive. There is also continuing concern about emissions of toxic air pollutants, such as benzene, which is released during the handling, storage, and combustion of fossil fuels, and mercury and other heavy metals, which are emitted during the combustion of heavy oil and coal.

A much cleaner source of energy, at least in terms of air pollution, is hydroelectric power, which supplies 12% of Canadian energy requirements. However, dams and reservoirs can seriously alter aquatic ecosystems. In addition, when uncleared or partially cleared land is flooded, decaying organic matter can eventually release considerable quantities of methane, a greenhouse gas 24.5 times more potent than carbon dioxide. Flooding also releases mercury from the soil, which may then work its way into the food web. Some of this mercury is of natural origin; in northern reservoirs, however, much of it can be traced to thermal power plants and factories in the industrial midwest of the North American continent, from where it was transported by air currents and deposited before the land was flooded (Lucotte et al. 1995).

A further 12% of the primary energy produced in Canada comes from nuclear power. Nuclear power facilities do not produce the atmospheric emissions associated with climate change that fossil fuel-fired facilities do. Like fossil fuel-powered generating plants, however, nuclear plants produce large amounts of waste heat. In fact, two-thirds of the heat produced in nuclear reactors is wasted, and only one-third is converted to electricity. Some of

Figure 11.36
Changes in types of energy consumption, 1970, 1981, and 1994



Notes: The joule is the basic unit for measurement of energy. A 30-L gasoline fill-up contains about one gigajoule (GJ) of energy.
A petajoule (PJ) is 1 million gigajoules.
Energy consumption = primary energy production plus imports minus exports.
The totals do not include net exports of electricity, which account for about 1.5% of total consumption.

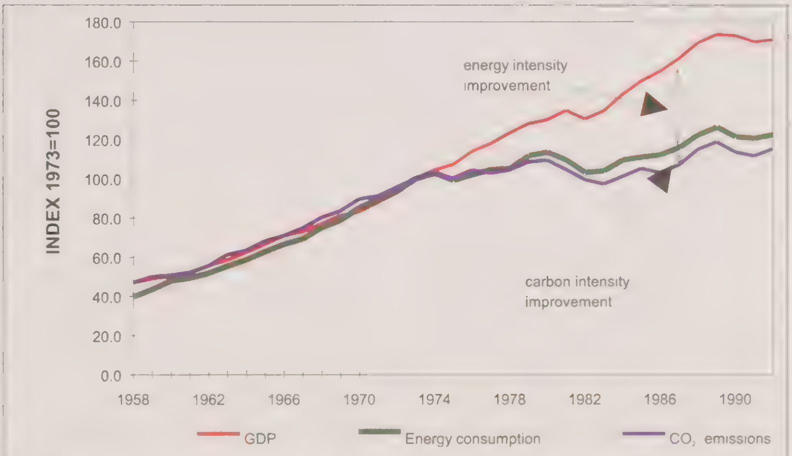
Source: State of the Environment Directorate, Environment Canada.

the waste heat, however, can be used for district heating.

A much more difficult problem is obtaining public acceptance for the disposal of nuclear fuel waste. True "walk-away" disposal methods are unlikely to be possible, given the long time periods (a minimum of 250 000 years) for which the longer-lived radionuclides would have to be isolated from the soil, air, and water. In planning repositories for nuclear fuel wastes, the possibility of incorporating technical improvements in the future is thus an important consideration. Such proposals are now being assessed.

Renewable energy also has some environmental impacts. Biomass (e.g., wood, which currently supplies about 6% of Canadian energy requirements) can contribute to local air pollution and waste disposal problems. Alternative energy technologies, such as active solar and wind power, cause less environmental stress per unit of energy than conventional sources. Although its environmental impacts have yet to be fully assessed, solar technology manufacturing, especially in the area of photovoltaics, has waste problems similar to those of other high-technology industries; in use, however, these devices are relatively free of problems. The main difficulties with wind energy involve impacts on habitat and the aesthetic impact of large wind farms. In the near term, wind and solar options are most likely to be used in remote community applications, because they are more cost-effective when an electric transmission grid is not already in place. While these alternative energy technologies are currently underutilized in Canada, they will increasingly help to reduce emissions of greenhouse gases and other air pollutants in the coming years.

Figure 11.37
Gross domestic product, energy consumption, and carbon dioxide emissions, 1958–1992



Notes: Energy intensity improvement is the difference between GDP and energy consumption
Carbon intensity improvement is the difference between energy consumption and CO_2 emissions.

Source: Statistics Canada; Environment Canada.

Atmospheric environmental issues

As Figure 11.38 shows very clearly, energy production and use are leading sources of atmospheric pollutants. These include carbon dioxide, methane, and nitrous oxide, which are greenhouse gases that contribute to climate change; sulphur dioxide, the principal contributor to acidic deposition; nitrogen oxides, which include nitrous oxide and are involved in both

Table 11.17
Canadian energy: annual growth rate 1971–1991 and projections to the year 2010

	Annual rate of growth (%), 1971–1991	Projections (%)	
		Natural Resources Canada,[a] 1992–2010	National Energy Board,[b] 1991–2010
Framework			
Population	1.2	1.1	1.1
Economic output[c]	3.4	2.6	2.5
World oil prices[c]	9.4	0.3	0.2
Fieldgate natural gas prices[c]	N/A	3.3	2.5
Overall domestic energy prices[c]	N/A	2.4	N/A
Energy demand[d]			
Total primary requirements	2.0	1.2	1.8
By end-use sector			
Residential	1.0	–0.1	0.7
Commercial	1.5	1.3	1.3
Industrial	1.5	2.1	1.9
Transportation	1.5	1.1	1.7
Nonenergy	N/A	2.1	1.6
By energy source			
Petroleum	0.2	1.0	1.6
Natural gas[e]	3.4	1.8	1.3
Coal	2.5	–0.2	3.1
Nuclear power	16.2	2.0	N/A
Hydro power	3.1	0.7	N/A
Renewable[f]	1.8	2.3	2.0
Energy production[g]			
Petroleum	0.6	0.3	0.3
Natural gas	3.0	2.0	2.0
Electricity	4.2	1.3	1.9

Note: N/A = not available.

[a] Reference scenario.
[b] Current technology scenario.
[c] In real terms (i.e., adjusted for inflation).
[d] Measured in joules.
[e] Includes liquefied petroleum gases.
[f] Other than hydro.
[g] Measured in volumetric units (i.e., cubic metres or watts per hour).

Source: Natural Resources Canada (1993, 1994c); National Energy Board (1994a, 1994b, 1994c).

acidic deposition and the formation of urban smog; and VOCs, particulates, and hydrocarbons, which also contribute to urban smog.

Approximately 90% of Canada's human-produced emissions of carbon dioxide, for example, arise from energy use, with fossil fuel use accounting for 98% of this total in 1992 (Environment Canada 1994b; National Energy Board 1994b). Energy-related sources also account for about 55% of sulphur dioxide emissions, about 90% of nitrogen oxide emissions, 55% of VOC emissions, and 35% of methane emissions (National Energy Board 1994b). Nitrous oxide is emitted in relatively small quantities, and estimates of total quantities emitted vary widely; overall, however, energy sources are thought to have accounted for about 50% of human-related nitrous oxide emissions in 1990 (National Energy Board 1994b).

Emissions of methane, sulphur dioxide, nitrogen oxides, and VOCs can be reduced by altering the technology of producing and/or using fossil fuels (National Energy Board 1994a). On the other hand, the production of carbon dioxide is an inherent part of the combustion of fossil fuels. Thus, the most effective way to cut carbon dioxide emissions is to cut energy consumption. As a panel of experts on greenhouse gas reduction has noted, "Improved energy efficiency is the key to stabilizing energy-related CO_2 emissions over the next two decades" (Royal Society of Canada 1993). The overall demand for energy can be reduced through more energy-efficient land use planning, transportation systems, and vehicles, through residential, commercial, and industrial building improvements, and through more energy-efficient industrial processes and technologies.

Climate change

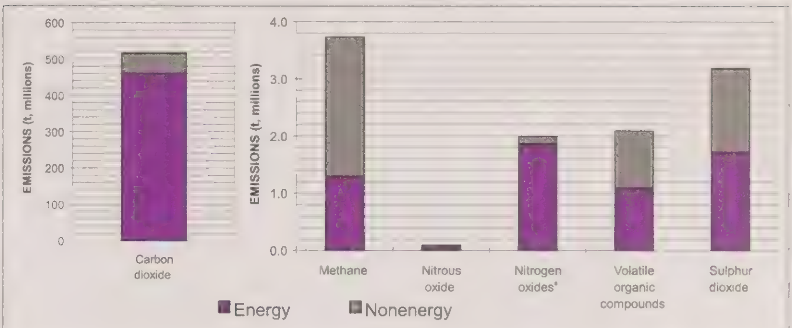
Of the three major energy-related greenhouse gases, carbon dioxide, nitrous oxide, and methane, carbon dioxide is of most concern. In Canada, most of the energy-related carbon dioxide emissions come from transportation, stationary combustion sources such as industrial boilers and residential and commercial space heating, and fossil fuel-fired power plants.

A number of factors influence a country's carbon dioxide emission level and emission growth rate. Five of the most important are the carbon intensity of energy consumption (emissions of carbon dioxide per unit of energy consumed), the energy intensity of economic activity (energy consumption per unit of economic output), growth in population, growth in economic activity, and the expansion of fossil fuel exports (including a growing share of sour [i.e., high sulphur] natural gas and heavy oil sands in the fuel mix).

Between 1958 and 1994, Canadian emissions of carbon dioxide from fossil fuel use increased by about 150%. As Figure 11.39 shows, carbon dioxide emissions rose with GDP until the mid-1970s. Then, following the oil price shock, both the energy intensity and the carbon intensity of the Canadian economy declined (Fig. 11.40) as improvements in energy efficiency were implemented and oil users began to switch

to natural gas (a less carbon-intensive fuel). As a result, carbon dioxide emissions slowed down during the rest of the 1970s and actually dropped in the early 1980s, even though GDP continued to rise. Emissions of carbon dioxide began to grow again, however, as the energy security issue waned. Both global and Canadian emissions of carbon dioxide increased by 12% between 1982 and 1991. Canada's share of global carbon dioxide emissions declined, though, from 2.2% in 1983 to 2.0% in 1992 (Environment Canada 1995b). For the world as a whole, the carbon dioxide growth rate is still much more closely tied to the economic growth rate than it is in Canada (Fig. 11.39), largely because of rapid industrial expansion in many of the developing countries that use coal and old technology.

Figure 11.38
Atmospheric emissions from human activity in Canada, 1990



*Nitrogen oxides (NOx) include the three common oxides of nitrogen — namely, nitrous oxide (N_2O), nitric oxide (NO), and nitrogen dioxide (NO_2)

Source: *Carbon dioxide, methane, and nitrous oxide*: Jaques (1992); *nitrogen oxides, volatile organic compounds, and sulphur dioxide*: L. Greenwood, Environmental Protection Service, Environment Canada, personal communication. The energy/nonenergy distinction is from National Energy Board (1994b).

Energy-related carbon dioxide emissions in Canada are poised to rise over the next 15 years if no new measures are implemented to reduce their growth. According to projections by Natural Resources Canada and the National Energy Board, which do not include National Action Program on Climate Change initiatives, such as the Voluntary Challenge and Registry Program, carbon dioxide emissions could exceed 1990 levels by 10–20% by the year 2000 and by 20–40% by 2010 (National Energy Board 1994a; Natural Resources Canada 1994c).

Energy-related emissions of methane (mostly from oil and gas production, coal mining, and incomplete fuel combustion) and nitrous oxide (almost entirely from fuel combustion) are also projected to increase in the future. However, because these estimates are more dependent on technological considerations, they are more uncertain than the estimates for carbon dioxide (Natural Resources Canada 1994c).

In 1992, Canada and other countries signed the United Nations Framework Convention on Climate Change (FCCC). This convention commits Annex 1 countries (Annex 1 countries, 36 in total, include most developed countries and countries with economies in transition, i.e., the former Soviet Union and eastern Europe) to work towards stabilizing national net (includes greenhouse gas sources and sinks) greenhouse gas emissions (except for those controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer) at 1990 levels by the year 2000; the target level for carbon dioxide emissions is noted on Figure 11.39. Canada is also pursuing opportunities to further reduce greenhouse gas emissions beyond the year 2000.

Governments have already taken a number of steps to meet this challenge. As part of its initial response to global warming, the federal government is implementing an Efficiency and Alternative Energy (EAE) program that emphasizes measures that make economic sense in their own right, apart from any contribution they might make to reducing greenhouse gas emissions. The program comprises 37 initiatives and employs a variety of instruments, including information, voluntary initiatives, research and development, and regulation (Environment Canada 1995e; Natural Resources Canada 1995e). However, it is estimated that these actions will not be enough to allow Canada to reach its stabilization target. Without taking into account the National Action Program on Climate Change, it is estimated that total greenhouse gas emissions could be 13% above 1990 levels by the year 2000 and 19% higher by 2005 (Royal Society of Canada 1995).

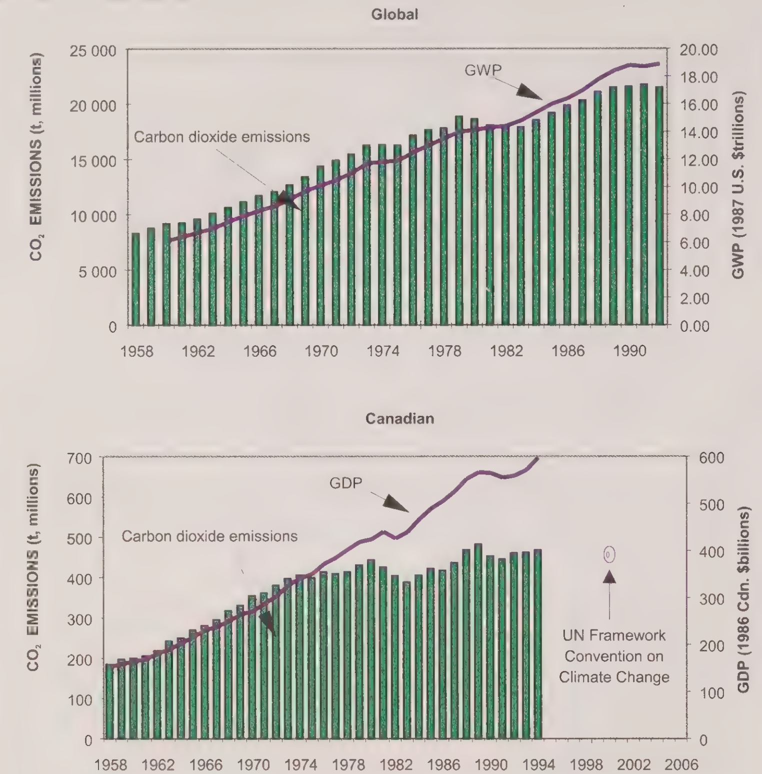
In February 1994, Canada published its *National report on climate change*, which identified actions being taken in Canada to meet commitments under the FCCC (Government of Canada 1994). The governments of Canada and the provinces are continuing to work with other stakeholders, such as business and environmental groups, to develop programs that will further reduce greenhouse gas emissions through voluntary, market-based, and regulatory actions and measures.

Canada is working, via its National Action Program on Climate Change, to achieve its commitment to stabilize net greenhouse gas emissions at their 1990 levels by the year 2000. Canada's progress will be reviewed regularly. The federal government will continue to work with provincial and municipal governments and non-government stakeholders to ensure that Canada is on track to meet its climate change commitments.

The National Action Program on Climate Change highlights ongoing and enhanced activities, new measures, and measures under consideration for future implementation. Critical elements of the program are the Voluntary Challenge and Registry

Figure 11.39

Carbon dioxide emissions from fossil fuel use: globally 1958–1992, Canada 1958–1994



Notes: Canadian emissions from biological sources of carbon dioxide (e.g., wood burning, domestic livestock, and landfills) are assumed to be in balance with the natural sinks that absorb carbon dioxide (e.g., oceans and forests).
GDP = gross domestic product.
GWP = gross world product.

Source: Environment Canada (1996c).

Program, Canada's Joint Pilot Initiative, and the Review Process (see Chapter 15 for more information on actions to control greenhouse gas emissions).

The challenge facing Canada, and Canadians, is formidable. According to the Royal Society of Canada's report entitled *Canadian options for greenhouse gas emission reduction (COGGER)* (Royal Society of Canada 1993), it is, however, economically feasible to achieve the interim target of stabilizing greenhouse gas emissions at 1990 levels by the year 2000 and to achieve an absolute reduction of 20% by the year 2010. Meeting the target, though, will require using all of the potential for cost-effective energy conservation and fuel switching that is available in the Canadian economy (Royal Society of Canada 1993, 1995).

Acidic deposition

Emissions of sulphur dioxide from energy use in Canada are associated mainly with fossil fuel combustion in the industrial, commercial, and residential sectors as well as the electricity-generating industry and the upstream oil and natural gas industries (particularly oil sands processing and natural gas production).

There has been significant progress since 1970 in controlling sulphur dioxide emissions in eastern Canada. In 1985, a Canadian Acid Rain Control Program was formalized by establishing federal–provincial agreements with the seven provinces east of Saskatchewan. The participating provinces agreed to reduce their combined sulphur dioxide emissions to 2.3 million tonnes per year by 1994. This target was achieved and surpassed in 1993 (Environment Canada 1996a).

In 1991, Canada signed an air quality agreement with the United States for the reduction of sulphur dioxide and nitrogen oxide emissions. Under the agreement, Canada is obliged to establish a permanent national cap on sulphur dioxide emissions of 3.2 million tonnes by the year 2000. Canada met this goal in 1993, and by 1994 sulphur dioxide emissions were down to about 2.7 million tonnes (Environment Canada 1996a) (see Chapter 10, Fig. 10.5).

Over the period 1970–1990, sulphur dioxide emissions from energy use were cut by approximately 30%, largely as a result of the wider use of lower-sulphur fuel (Fig. 11.41). However, because emissions from nonenergy sources were cut by close to 65%, owing largely to changes in the nonferrous metal smelting industry, the share of total Canadian sulphur dioxide emissions from energy use rose from 37% to 55% between 1970 and 1990.[2]

The most significant reductions occurred in eastern Canada, where the acidic deposition problem is greatest. In western Canada, sulphur dioxide emissions have grown, and much higher emissions are forecast for the 1995–2000 period and beyond as a result of further sour gas processing, oil sands development, and thermal electricity generation (R. MacIntosh, Pembina Institute for Appropriate Development, personal communication).

2. Three emission inventories (1970–1980, 1985, 1990) were used to calculate these figures. Some of the change could be attributed to differences in inventory methods.

Between 1970 and 1990, sulphur dioxide emissions declined for most energy applications, except for emissions from thermal electric power generating plants, which increased by 25%. Power plant emissions started to decline in 1984; since 1990, several additional plants have been fitted with sulphur dioxide control systems, which should further reduce emissions in eastern Canada.

According to the National Energy Board, energy-related emissions of sulphur dioxide should continue to decline until 2010.[3]

The National Energy Board expected a large decline in power plant emissions of about 25% between 1992 and 2010, as a result of provincially mandated legislative limits.

In 1995, Canada began developing a national strategy on acidic deposition for the post-2000 period. This strategy will be considered by federal and provincial/territorial energy and environment ministers in 1997 (Environment Canada 1996a).

Figure 11.40

Change in energy intensity and carbon intensity for selected industrialized countries, 1973–1992

Notes: OECD = Organisation for Economic Co-operation and Development
IEA = International Energy Agency
OECD/IEA includes the 24 countries noted above

Source: International Energy Agency, calculations by A. Coombs, Energy Sector, Natural Resources Canada

Urban smog

Ground-level ozone is a key ingredient of urban smog. It is not emitted directly to the atmosphere but is formed by a complex series of reactions involving nitrogen oxides, VOCs, and sunlight. Energy-related emissions of nitrogen oxides stem almost entirely from fuel combustion, from both transportation and stationary sources. Energy-related VOCs are released during the production, transport, storage, and combustion of petroleum fuels. Although nitrogen oxides and VOCs are derived from many sources, gasoline- and diesel-powered vehicles account for about half of total anthropogenic emissions.

In contrast to the marked decline in sulphur dioxide emissions, nitrogen oxide emissions (which are almost entirely from energy-related sources) increased by about 44% between 1970 and 1980 and have remained relatively constant since then (Fig. 11.41). The increase in the number of automobiles, trucks, and off-road vehicles has been the main factor driving the growth of nitrogen oxide emissions, and it is only because of more stringent vehicle exhaust controls that emissions stabilized in the 1980s.

The National Energy Board expects energy-related nitrogen oxide emissions to rise moderately to the year 2010. Lower automobile emissions resulting from improved engine technology are not expected to fully offset the increase in emissions anticipated as a result of higher total energy consumption. Therefore, by 2010, nitrogen oxide emissions could be 10% above 1992 emission levels (National Energy Board 1994b).

Emissions of energy-related VOCs have not declined in recent years, but they are expected to do so in the future. According to the National Energy Board, energy-

3. The National Energy Board projections include only emissions emanating from the electric power sector and the upstream oil and gas sector (i.e., oil and natural gas production activities): emissions arising from fuel combustion in the residential, commercial, industrial, and transportation sectors are not included. In the early 1990s, the excluded sectors accounted for about 15% of total sulphur dioxide emissions and about 30% of energy-related emissions.

related VOC emissions could be 17% lower in 2010 than in 1992. The decline is predicated on an 18% reduction in transport sector emissions as a result of improved emission controls and a 22% reduction in the oil and gas sector as a result of reduced oil production (National Energy Board 1994b).

In 1990, the Canadian Council of Ministers of the Environment agreed in principle on a comprehensive management plan to control nitrogen oxide and VOC emissions (CCME 1990). In particular, it was agreed that, by 2005, national nitrogen oxide emissions would be reduced by 11% and VOC emissions by 16% from 1985 emission levels. More ambitious targets, involving reductions of between 25% and 40%, were also set for the more seriously affected areas, such as the lower Fraser Valley of British Columbia, the Windsor–Quebec City corridor, and the area around the Bay of Fundy in the Maritimes (CCME 1990).

In order to reduce VOC emissions, six provinces have already legislated limits on the volatility of gasoline sold within their jurisdictions.

Other pollutants: toxic air pollutants
Some of the petroleum products that Canadians have come to rely upon either contain or produce toxic airborne substances. These substances can be harmful to human health and detrimental to the health of ecosystems. In the past, lead in gasoline was of particular concern. Today, the energy-related substances of most concern include cadmium and other heavy metals, as well as benzene and related compounds (toluene, xylene, and ethylbenzene) and carbon monoxide (CO).

About 70% of total carbon monoxide emissions in Canada are energy related, and well over 60% of total carbon monoxide emissions are attributable to the combustion of hydrocarbons in the transportation sector, notably in gasoline-powered vehicles. Control devices on large point sources as well as oxidation catalysts on automobiles, which were introduced in the 1970s, have reduced the overall growth rate of emissions in recent years. Between 1979 and 1993, average carbon monoxide levels fell by 55% (Environment Canada 1996b).

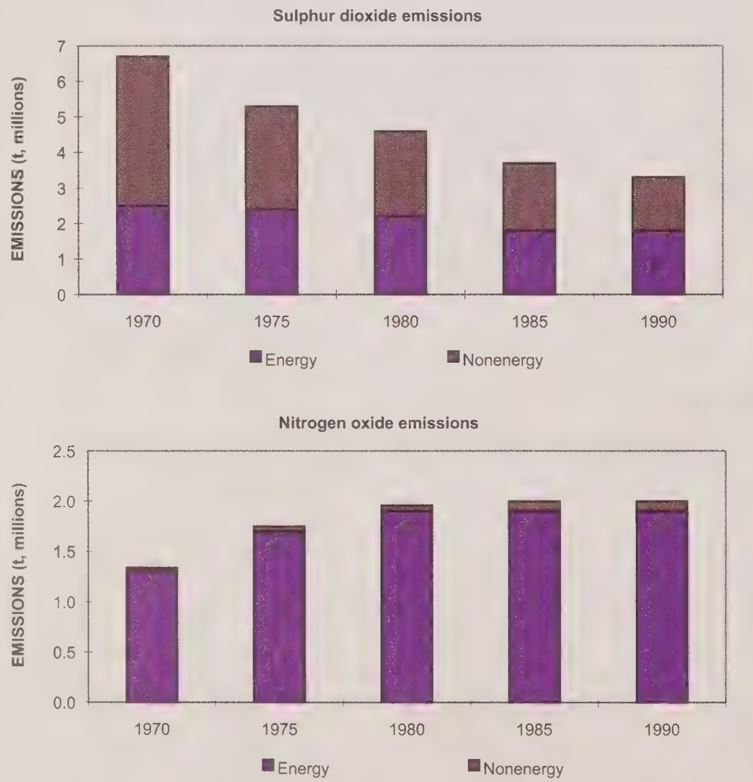
Coal contains trace amounts of several toxic substances, such as cadmium, arsenic, and mercury. Portions of these pollutants are emitted as fine particulates when they escape the control devices.

Benzene, a known carcinogen, was classified as a toxic substance under the *Canadian Environmental Protection Act* (CEPA) in 1994. It is used in a variety of applications in Canada and can enter the environment through air, water, and land releases. Over 95% of human-produced releases, however, take the form of air emissions (Environment Canada and Health and Welfare Canada 1993).

Benzene is a component of crude oil and natural gas as well as of refined petroleum products such as gasoline. In 1994, for example, benzene made up 1–3% of the volume of Canadian gasoline (Canadian Petroleum Products Institute 1994). It can enter the air as a result of both evaporation and incomplete combustion.

Over 90% of airborne benzene emissions are energy related. Dehydration of natural gas with glycol (primarily in Alberta) is responsible for about 30% of Canadian emissions. About 55% of total benzene

Figure 11.41
Emissions of sulphur dioxide and nitrogen oxides, 1970–1990



Source: Environment Canada (1986); Kosteltz and DesLauriers (1990); unpublished data, Pollution Data Branch, Environmental Protection Service, Environment Canada.

emissions originate in the transport sector, with gasoline-powered vehicles responsible for over 50% of total emissions (Environment Canada 1993a; M. Tushingham, Environmental Protection Service, Environment Canada, personal communication).

Benzene emissions are on the decline. Between 1985 and 1991, emissions were reduced by 35%, from 34 to 22 kt/year, primarily as a result of improved automobile engine efficiency and vehicle pollution control devices (Environment Canada 1993a). Between 1989 and 1994, average benzene concentrations in Canadian cities fell by more than one-third. Concentrations were generally four times higher in city centres than in rural areas (Environment Canada 1996b, from data supplied by T. Dann, Environmental Protection Service, Environment Canada). Emissions are expected to continue to decline as a by-product of continuing efforts to reduce VOC emissions from both mobile and stationary sources and combat urban smog.

In summer 1995, the federal Minister of the Environment announced accelerated action on regulations to limit benzene releases into the environment. Federal regulations will be developed under CEPA to limit the benzene content of gasoline to 1% by volume. It is estimated that this action will cost between 0.2 and 0.4 cents per litre. The regulations will also limit any increase in the amount of benzene-related compounds in gasoline. This is expected to reduce emissions of benzene from vehicles by about 20%. These new requirements will give Canada the best national gasoline standards for benzene in the world (Environment Canada 1995c).

Nonatmospheric environmental issues

Energy supply systems can affect land and water resources in a variety of ways. These include the physical restructuring of landscapes, the diversion of river systems and the flooding of large tracts of land, soil compaction and erosion, the discharge of liquid effluents and wastes, accidental spills and leakages of harmful substances on land and in water, and the loss of water and land-based habitat.

Land disturbances and pollution

Oil and gas production

In 1992, about 80% of the oil produced in Canada was conventional oil, recovered by means of wells drilled into subsurface reservoirs. The remaining 20% was nonconventional oil, recovered from oil sands deposits in Alberta in the form of bitumen and synthetic oil (Fig. 11.42). Almost all of the oil produced in Canada came from the Western Canada Sedimentary Basin (WCSB) (Fig. 11.43).

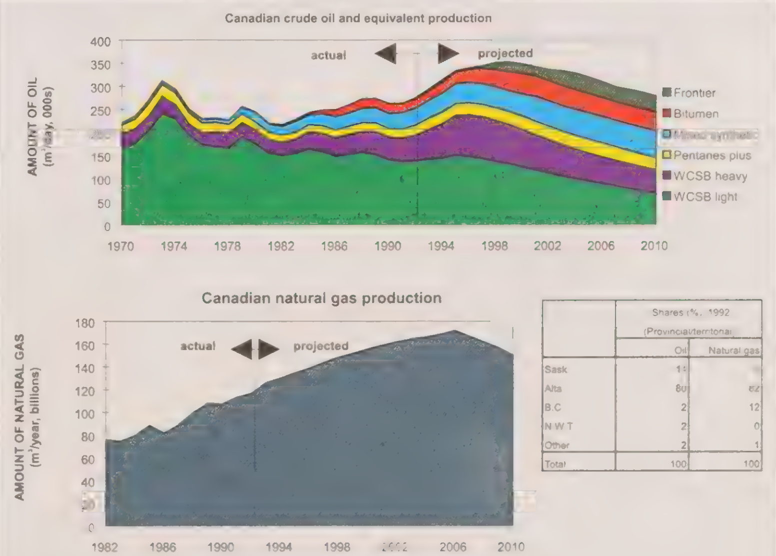
In addition to the sedimentary deposits in western Canada, there are significant unexploited conventional oil resources in Canada's North and offshore regions (denoted as frontier oil in Fig. 11.42; see also Fig. 11.43). The Arctic contains 59% of Canadian oil reserves as well as 49% of the potential gas reserves. If these become an important component of Canadian oil supply in the future, the environmental ramifications for Arctic ecosystems, both terrestrial and aquatic, could be severe. The Hibernia project, located offshore from Newfoundland, is already under development, and oil production could start there in 1997.

About one-fifth of the recoverable oil from Canada's oil sands is located close to the surface. For this portion of the resource, the production process involves surface mining of the oil sands, processing the oil sands to separate the oil and bitumen from the sands, and upgrading the bitumen to higher-grade oil for sale to refiners (denoted as mined synthetic production in Fig. 11.42).

For the other four-fifths of the resource, "in situ" production techniques are used (represented as bitumen production in Fig. 11.42). The production process generally involves injecting steam through vertical and horizontal wells into the subsurface oil sands deposits. This lowers the viscosity of the bitumen so that it can be pumped more easily to the surface.

Figure 11.42

Historical and projected Canadian oil and natural gas production



	Shares (%, 1992 (Provincial/territorial)	
	Oil	Natural gas
Sask	[illegible]	[illegible]
Alta	80	82
B.C	2	12
N W T	2	0
Other	2	1
Total	100	100

Note: WCSB = Western Canada Sedimentary Basin.

Source: National Energy Board (1994a, 1994b, 1994c).

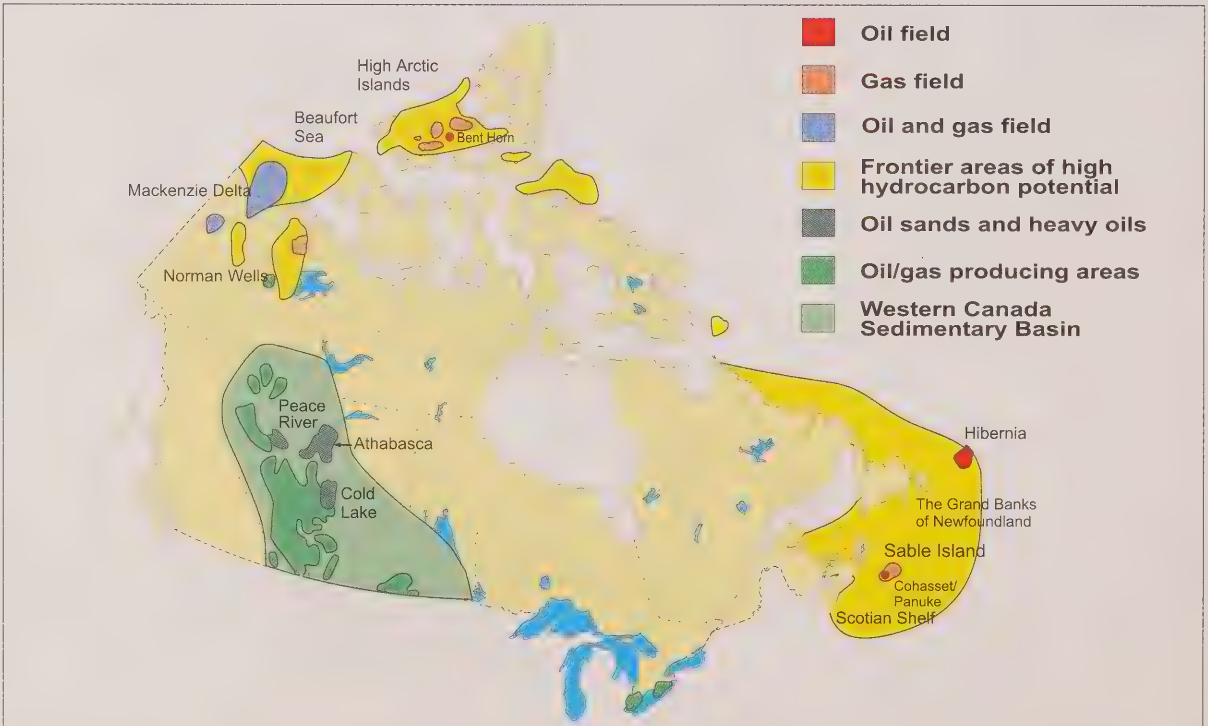
Canada's commercial natural gas reserves are located almost entirely in western Canada. In 1992, Alberta accounted for about 82% of total Canadian production, with the remainder coming mainly from British Columbia (12%). Most incremental production to meet growing domestic and export demand for the foreseeable future is also likely to come from western Canada (Fig. 11.42). Canada's frontier regions are not expected to produce significant commercial quantities of natural gas for the next 10–20 years.

Environmental effects on land associated with conventional oil and gas exploration, development, and production in Alberta tend to involve land use conflicts with critical wildlife areas and endangered species. With new technologies such as horizontal drilling, however, a number of wells can be drilled from a single pad, thereby minimizing the amount of land that is disturbed.

Most surface disturbances can eventually be mitigated altogether by land reclamation after wells have been abandoned (about 100 000 oil and gas wells, including 1 050 wells in Canada's northern territories, have been abandoned to date). Reclamation is a requirement of both federal and provincial regulations, which also stipulate that wellheads be removed, casings cut, and wells capped. Today, companies are also practising "ecosystem" reclamation, which consists of using native plants when reclaiming land rather than simply using domestic grasses for erosion control.

Although the total land surface disturbed by (conventional) oil and gas well activity seems relatively modest, oil and gas exploration and development are a major cause of wilderness destruction. For example, in Alberta, an estimated 150 000 active and inactive oil and gas wells cover about 150 000 ha or about 0.23% of the province's land area (Province of Alberta 1994). Oil production not only removes land from alternative uses but introduces a number of other environmental stresses, including oil spills, the disposal of toxic chemicals used in drilling "muds," soil compaction, the use of soil sterilants and herbicides, and the release of sour gas (Government of Canada 1991). About 10 000 m^3 of oil per year, equivalent to about 0.01% of total crude production, are released in oil-producing areas of Canada through spillages or well blowouts (Statistics Canada 1994b).

Figure 11.43
Oil and gas resource areas



Source: Government of Canada (1991); B. Young, National Energy Board, personal communication.

Oil sands projects tend to disturb more land per unit of oil produced than conventional oil and gas projects. This is because the bitumen has to be mined by surface mining techniques, leading to large quantities of overburden and oil sands tailings for disposal. It takes, on average, about 9–12 m^3 of extracted oil sands to produce 1 m^3 of bitumen, which then has to be processed and upgraded in a synthetic processing facility.

In addition to physically disturbing or restructuring the land, oil sands mining projects can also give rise to additional environmental problems associated with the disposal of the large quantities of tailings — in particular, contaminated sludge (fine tails) produced during the processing stage. The sludge, which contains metallic compounds and acid, is toxic to aquatic life and has to be impounded and isolated in tailings ponds. These ponds cannot easily be reclaimed because they retain their watery consistency for years.

Oil and gas pipelines

Because sources of hydrocarbons (oil and natural gas) are usually far removed from major consumption centres, an extensive transportation infrastructure, consisting of pipelines, pumping and compressor stations, and measuring facilities, traverses the Canadian landscape. With approximately 36 000 km of oil pipelines and 255 000 km of gas pipelines (excluding producer field gathering pipelines), the network is extensive, even when compared with Canada's 889 000 km of roads (Statistics Canada 1994b).

The construction of pipelines can result in short- and long-term disturbances to the land surface and in disturbance to wildlife or alteration of their habitat (Government of Canada 1991). The key issue is habitat and wilderness fragmentation and the increased access to natural areas caused by newly cut corridors through the woods, which, if used frequently, may not regenerate back to forest. However, the impact of pipelines is generally less than that of roads. In addition, many pipelines are aging, and corrosion may occur. Proper maintenance and operation will be necessary to ensure that leaks are rare events and that, when they do happen, the environmental impacts are minimized and dealt with promptly.

Coal production

In Canada, nearly all coal mines are surface mines (strip or open pit). In 1993, they accounted for about 93% of total Canadian production, with the remaining 7% coming from underground mines. The three most westerly provinces accounted for over 90% of total production, with Nova Scotia and New Brunswick responsible for most of the remainder. Alberta was the largest producer, with over 50% of Canadian production.

Close to 70% of the coal produced in Canada is thermal coal, used predominantly for the generation of electrical power. The remainder is metallurgical coal, used primarily in the manufacture of iron and steel (Fig. 11.44).

Open pit mining and, to a greater extent, strip mining involve the removal of vegetation, relocation of overburden, and removal of land from wildlife habitat or agricultural use. However, coal mines disturb but a small fraction of the total land area. For example, in Alberta as of 1993, coal mining had disturbed about 15 000 ha, of which about 7 000 ha have been reclaimed.

Moreover, the disturbance is temporary. Once the ore body is depleted and mining activities cease, companies are required to reclaim mined-out areas. The industry has developed specialized reclamation techniques suited to the topography and desired end use of the land. In the mountains and foothills, land is usually restored to wildlife habitat or forestry uses; on the prairies, it is generally returned to agricultural use.

Coal in its raw form contains noncombustible inorganic material, which, in most cases, must be removed or washed out in cleaning plants prior to use. This inorganic material, along with large quantities of cleaning water, has to be collected, controlled, and treated. For every 10 t of coal produced, 2 t of coal waste are generated. In 1991, close to 20 Mt of coal waste were generated in Canada (Statistics Canada 1994b).

Today, the waste material is usually used as backfill in land reclamation, but in the past it was frequently allowed to remain in piles after closure of the mine site. Natural reclamation of these waste piles has sometimes been slow, because the material has been unsuitable for plant growth.

Water disturbances and pollution

Hydroelectric power

Canada is blessed with an abundance of rivers with waterfalls and rapids suitable for the generation of hydroelectric power. In 1994, about 61% of the electricity generated in Canada was hydroelectric. Another 18% was produced by fossil fuel generation (15% from coal, 2% from natural gas, and 1% from oil), 19% by nuclear generation, and the rest by alternative and renewable sources such as biomass and wind (Po-Chih Lee, Energy Sector, Natural Resources Canada, personal communication).

As of 1991, of the 650 largest dams in Canada, over 70% were used for electricity generation, and 9 out of every 10 dams constructed between 1970 and 1991 were for purposes of hydroelectric power generation (Table 11.18 and Fig. 11.45).

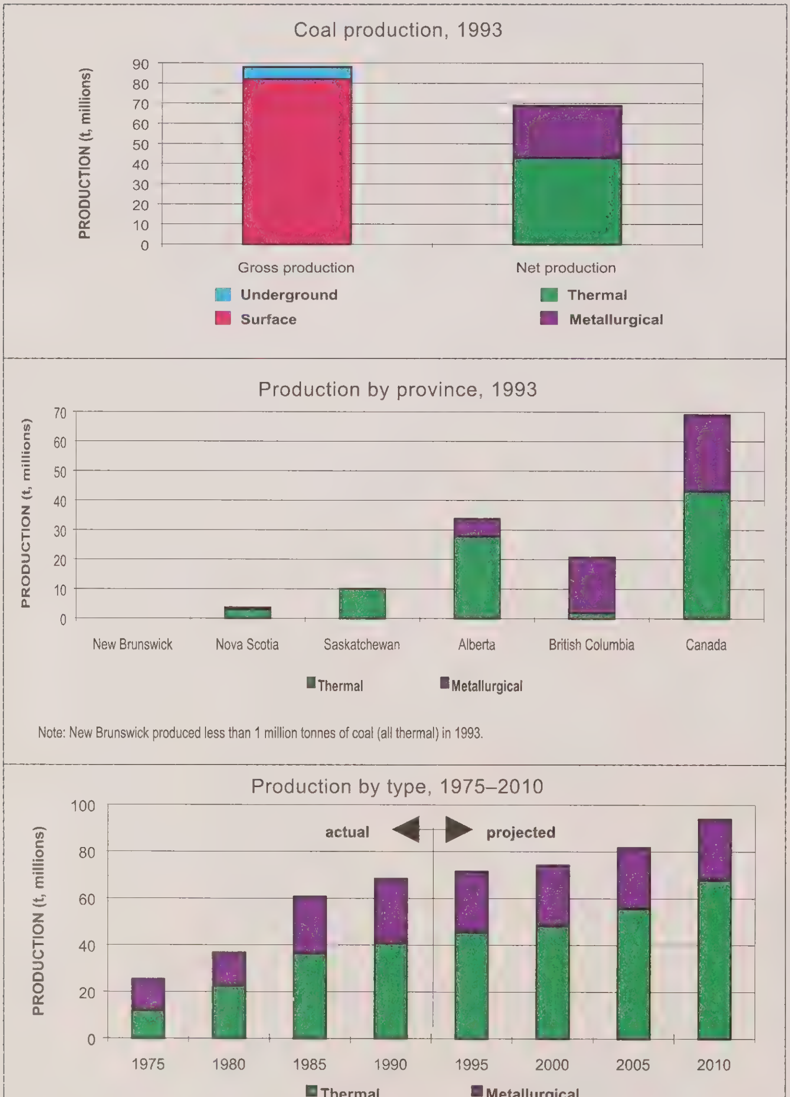
Similarly, the 54 largest water diversion projects in Canada were undertaken predominantly for energy purposes, with about 96% of the total diverted water flow being used for the generation of electric power (Table 11.19). The total flow of these 54 diversions, if combined, would qualify as Canada's third largest river, after the Mackenzie and St. Lawrence rivers (Statistics Canada 1994b).

Three hydroelectric projects, the Churchill Falls Project in Newfoundland/Labrador, the Churchill–Nelson Diversion Project in Manitoba, and the La Grande River (James Bay Phase 1) Project in Quebec, account for about two-thirds of the total water diverted. Although the number of suitable sites for development is getting smaller, there is still considerable

undeveloped hydro potential at numerous existing and new sites, notably in Labrador, Quebec, Manitoba, and British Columbia, and it is possible that additional hydro capacity will be developed (Box 11.17). A federal environmental review process would be necessary, however, before any future hydroelectric development was undertaken.

Hydroelectric power is often promoted as an environmentally benign source of power, but the restructuring of water systems by dams and diversions can alter river flow rates, expose riverbeds to erosion, and contribute to the loss of land resources and the destruction of wildlife and fish habitat. The flooding of forest and peat lands also contributes to the release of carbon dioxide and methane. (For a more detailed discussion of the environmental concerns associated with dams and diversions, see the "Fresh water" component of Chapter 10.)

Figure 11.44
Canadian coal production



Notes: Net production is gross production minus waste.
Thermal coal is used to generate electricity.
Metallurgical coal is used in the smelting and steelmaking industries.

Source: Energy, Mines and Resources Canada (1993b); National Energy Board (1994a, 1994b, 1994c); Statistics Canada (1995a).

One of the most serious problems is the mobilization of mercury and other harmful elements when water is impounded to create reservoirs. The bacteria that thrive in the presence of flooded vegetation of new reservoirs transform elemental mercury into toxic methylmercury. This eventually accumulates in the flesh of edible fish and is passed on to the people and animals that eat them.

Because fish are a major component of their diet, Native peoples living in watersheds affected by hydro development are most at risk. Exposure tends to be seasonal but chronic and is highest in the late summer and early fall. This seasonal exposure pattern may have prevented the mercury problem from becoming acute, as the body is able to rid itself of accumulated mercury during the low-exposure season.

Problems of mercury exposure are currently most serious among the Cree of northern Quebec, who inhabit the area affected by the giant James Bay development. Average mercury concentrations in whitefish taken from hydroelectric reservoirs in the area range from 0.06 to 0.21 ppm, whereas those in Northern Pike are 3.0 ppm or higher (Bodaly and Johnston 1992). Fish containing more than 0.5 ppm are considered unsafe for continued long-term consumption and cannot be sold in Canada.

Two blood mercury screening programs, carried out in 1971–1978 and 1979–1982, showed that 40% of the Native population of Quebec had blood mercury levels higher than the 20 ppb acceptability criterion set by the World Health Organization, whereas 80 individuals (less than 1% of

the Native population) had levels in the danger zone, above 200 ppb (Hydro-Québec 1993). In the rest of Canada, the number of First Nations people above the 20 ppb threshold declined to zero during the 1979–1982 survey (Hydro-Québec 1993). Since 1984, the Cree have been advised to reduce their intake of fish, and there has been a gradual decline in blood mercury levels in the population.

Elevated fish mercury levels may or may not be transitory. As yet, there are no published data that demonstrate both a rise in mercury levels in fish immediately after impoundment and a subsequent decline to preimpoundment levels as the reservoir ages (Jones et al. 1986). Atmospheric mercury depositions and mercury remobilization from sediments may prevent levels from returning to pre-impoundment levels for decades or for the lifetime of the reservoir (Lockhart 1992; Lucotte et al. 1995). Further information on the effects of mercury on humans and the natural environment may be found in Chapters 5, 8, 10, and 13.

Oil spills

Oil spilled at sea or in fresh water can be very damaging to the environment, particularly in the short term. For example, spills can coat shorelines, damage fish spawning areas, severely affect wildlife, and destroy microscopic organisms that anchor the food chain (Government of Canada 1991).

Based on current tanker traffic levels, it has been estimated that Canada can expect over 100 small oil spills (<1 t), 10 moderate spills (1–100 t), and at least one major spill (100–10 000 t) every year. A catastrophic spill (over 10 000 t) is likely once every 15 years (Public Review Panel on Tanker Safety and Marine Spills Response Capability 1990). For comparison, the tanker *Exxon Valdez* spilled approximately 35 000 t of oil in Prince William Sound, Alaska, in 1989.

Between 1988 and 1994, 2 732 spills of petroleum-based materials were reported along Canada's east coast. The amount of material spilled in almost three-quarters (1 966) of these cases is not known. However, for the remaining one-quarter (766 occurrences), about 20 000 t of petroleum products were spilled in total (L. Trip, Environment Canada, personal communication). In 1970, the tanker *Arrow* spilled 8 000 t of bunker C fuel oil in Chedabucto Bay (Nova Scotia); in 1979, the *Kurdistan* spilled the same amount off the coast of Nova Scotia.

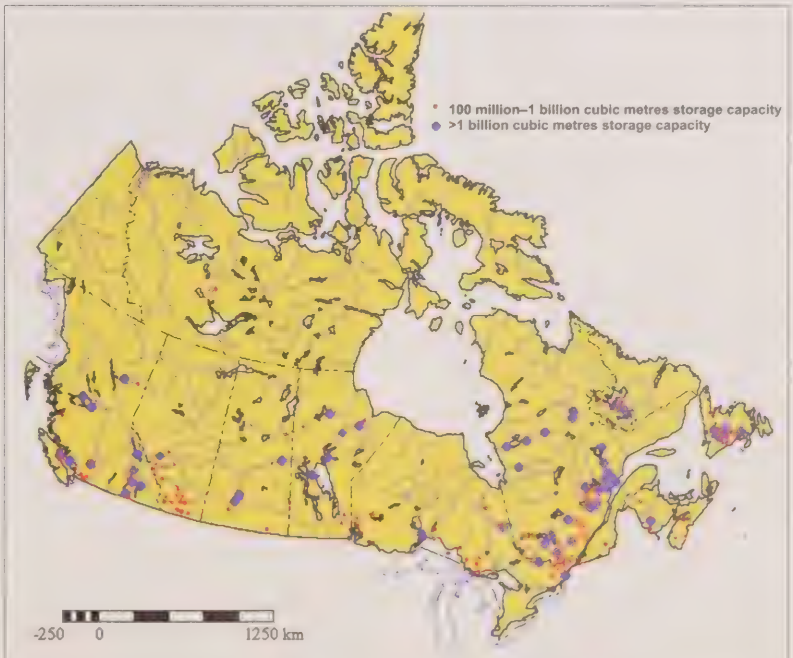
Table 11.18
Number of large dams constructed in Canada by 1991

	No. of dams			
	Up to 1975	1976–1991	By 1991	% of total
Irrigation	48	10	58	9
Hydroelectric	331	128	459	71
Flood control	19	5	24	4
Water supply	40	9	49	7
Recreational	5	2	7	1
Other	52	1	53	8
Total	495	155	650	100

Note: Large dams are defined by the International Commission on Large Dams as any dam higher than 15 m, as well as dams between 10 and 15 m in height, provided one of the following conditions is met: (a) length of crest (top) of the dam is greater than 500 m, (b) reservoir capacity is greater than 1 million cubic metres, (c) maximum discharge is greater than 2 000 m^3/s.

Source: Canadian National Committee of the International Commission on Large Dams (1984, 1991); Statistics Canada (1994b).

Figure 11.45
Largest dams in Canada, 1991



Source: Canadian National Committee of the International Commission on Large Dams (1984, 1991).

Although Canada has so far escaped a catastrophic oil spill such as the *Exxon Valdez* spill in Alaska or the *Amoco Cadiz* spill off Brittany, France, the risks are always present. In 1988, for example, the tanker *Athenian Venture* sank about 600 km off the coast of Newfoundland, releasing 30 000–35 000 t of gasoline and bunker fuel oil into the ocean (almost as much as the *Exxon Valdez* spill). Had such a spill occurred closer to shore, the impact on aquatic and terrestrial ecosystems could have been very serious.

Offshore wells present an additional risk. More than 375 of them have been drilled off the east coast of Canada and in the Arctic. Although most were exploratory wells that have since been abandoned, significant oil discoveries have been made (Environment Canada 1994c). Currently, small quantities of oil are being produced at the Cohasset/Panuke Project, 150 km off the Nova Scotia shore. As well, Hibernia is scheduled to come into production in late 1997 or early 1998.

According to industry estimates, the probability of a major oil well blowout is about 1 in 7 000 wells drilled (Environment Canada 1994c). Once production starts, major oil spills can also occur as oil is produced, stored, and loaded onto tankers for delivery to refineries. As much as 92% of all oil spills involving tankers happen at a terminal when oil is being loaded or discharged (Environment Canada 1994c).

Table 11.19
Interbasin water transfers, by province, 1990

Province	No. of diversions[a]	Average annual flow (m^3/s)	Major use	Flow diverted for major use as a % of total
Newfoundland	5	725	Hydro	100
New Brunswick	2	2	Municipal	70
Nova Scotia	4	18	Hydro	100
Quebec	6	1 854[b]	Hydro	100
Ontario	9	564	Hydro	89
Manitoba	5	779[c]	Hydro	97
Saskatchewan	5	30	Hydro	85
Alberta	9	117	Irrigation	53
British Columbia	9	361	Hydro	89
Total	54	4 450		96

[a] Includes only diversions that meet the following criteria: the diverted flow does not return to the stream of origin within 25 km of the point of withdrawal, and the mean annual diverted flow is not less than the rate of 1 m^3/s. There were no interbasin transfers in Prince Edward Island, Yukon, and Northwest Territories.
[b] Excludes Beauharnois Canal flows from the St. Lawrence River.
[c] Excludes floodway flows (Portage Diversion, Winnipeg Floodway, Seine Diversion) of short duration.

Source: Day and Quinn (1992); Statistics Canada (1994b).

Box 11.17
Great Whale and Kemano hydroelectric power projects

Hydro-Québec has been assessing the feasibility of harnessing the hydroelectric potential of the Grande rivière de la Baleine (Great Whale) in northern Quebec since the 1970s. The project, as first proposed, would have required the flooding of 2 923 km² of land. Although the proposed project was eventually scaled back in 1993, it would have still required the flooding of 1 667 km² of land. As well, flooding would have affected an additional 1 724 km² of aquatic environment. This is equivalent to well over half of the total land area of Prince Edward Island. Because of a decreasing demand for electrical power and political considerations, the Government of Quebec in late 1994 put the project on hold.

Likewise, the Government of British Columbia intervened in late 1994 to stop work on Alcan's Kemano Completion Project in northwestern British Columbia. Of particular concern to the B.C. government was the potential impact that a further diversion of water from the Nechako River would have on salmon spawning habitat and its possible consequences for communities dependent on this fishery. The river flow had already been reduced by an earlier project, the Kemano 1 Project (Gomez-Amaral and Day 1987).

Petroleum refining and retailing

A wide range of organic and metallic pollutants can be found in refinery wastewaters. Many of the contaminants originate in the crude oil itself, whereas others are produced during refining. Still others are products of corrosion associated with the processing equipment or are chemicals employed in refinery operations.

Contaminants in oil refinery effluents are controlled by both federal and provincial legislation. Over the past two decades, Canadian oil refiners have substantially reduced conventional contaminants in their wastewaters. Between 1980 and 1994, discharges of phenols were reduced 74%, oil and grease 72%, sulphide 71%, ammonia nitrogen 65%, and total suspended matter 57% (St-Cyr 1996).

Despite this positive record, concerns persist regarding discharges of carcinogenic substances like polycyclic aromatic hydrocarbons (PAHs) and other potentially toxic organic and metallic contaminants. The extent and seriousness of the problem, and what should be done about it, are currently being discussed by federal and provincial governments and industry.

The retail end of the refining industry has made progress in upgrading petroleum transportation and storage systems in an effort to reduce VOC emissions and potential groundwater and soil contamination. Underground tank storage systems and refilling systems, such as those

at local gas stations, have received particular attention (Petroleum Communication Foundation 1993). In the past, steel underground storage tanks and piping systems have frequently leaked owing to corrosion and other failures. These leaks often went unnoticed until the symptoms of a serious environmental problem were evident. Today, a more proactive pollution prevention approach is the norm. It is expected that, by the year 2000, most underground storage tank systems in Canada will have been significantly upgraded to meet the higher standards of protection developed by the Canadian Council of Environment Ministers, thereby reducing the risk of groundwater and soil contamination.

Coal mining and transportation

Coal mining and transportation generate large quantities of coal dust and other fine particles that can be hazardous to those who come into contact with them on a daily basis. Surface mining can also release these particles into the surrounding atmosphere, thus contributing to local air pollution. Measures are taken to control coal dust.

Water is often used to spray underground mines, surface coal areas, and access roads. All mine water, including runoff and pit-water, is collected in settling ponds and treated according to federal and provincial regulations before being released into surrounding rivers, streams, and lakes. Uncontrolled discharges may accidentally occur, resulting in water quality objectives for potentially damaging substances not being met.

Another water-related problem is acid drainage from coal mines. This is mainly a problem in eastern Canada, where coal deposits contain significant amounts of sulphides, the main cause of acidification. It is not of major concern in western Canada, where most coal is mined, because coal deposits there have a low sulphide content. Where acid mine drainage is potentially a problem, mining companies are required to operate comprehensive systems to collect and treat acidic effluents and seepage. A more detailed discussion of acid mine drainage is found in the "Minerals, metals, and mining" component of this chapter.

Nuclear power and wastes

Electricity generated from nuclear energy does not contribute to emissions of noxious and polluting gases, such as carbon dioxide, nitrogen oxides, and sulphur dioxide. However, because of safety risks associated with the use of nuclear energy (the 1986 Chernobyl accident is an important reminder in this regard), the nuclear industry is one of the most intensely regulated industries in Canada. The federal government established the Atomic Energy Control Board (AECB) to regulate the development, application, and use of nuclear energy in Canada. The AECB derives its authority from the *Atomic Energy Control Act* of 1946, the most important piece of legislation pertaining to Canada's nuclear program. The general approach to safety, including radioactive waste management, is that the producer/owner is responsible for complying with regulatory criteria. The Canadian nuclear industry has adhered to the strict standards and procedures required by the AECB, and, as a result, Canada has an excellent record in protecting the environment and health of the public and workers who operate these facilities. Nevertheless, risks are always present.

Broadly speaking, there are three types of nuclear wastes associated with the nuclear fuel cycle: low-level radioactive tailings generated by uranium mining and milling operations; low-level radioactive waste (LLRW) associated with other phases of the nuclear cycle (e.g., contaminated garbage from operations and maintenance activities, filters, process residues, and irradiated equipment); and nuclear fuel wastes (NFW), consisting mainly of spent nuclear fuel rods. NFW are materials that are highly radioactive and may be capable of emitting radiation for tens of thousands of years.

As of 1992, there were approximately 203 Mt of low-level radioactive tailings, covering 1 570 ha of land (or approximately 16 km^2), stored at various active and inactive uranium mining and milling sites in Canada, mainly in Ontario and Saskatchewan (Table 11.20).

There were an additional 1.3 million cubic metres of LLRW, attributable to other stages of the nuclear cycle (i.e., the post-mining/milling stages). Most of this waste, 1.16 million cubic metres, was contaminated soil generated by past activities. The remainder consisted of contaminated materials, residues, and irradiated equipment from nuclear processing facilities, power plants, industrial and medical facilities, and research laboratories (Table 11.21).

All NFW in Canada are currently stored at nuclear reactor sites. As of 1994, there were more than 900 000 bundles of NFW in storage in Canada, most of it owned by Ontario Hydro (Atomic Energy of Canada Limited 1994).

The on-site storage of NFW may be adequate for the short to medium term but not for the long run. As some of these wastes will remain radioactive for thousands of years, a method to dispose of these and contain their radioactivity permanently will have to be found. At present, the Canadian Environmental Assessment Agency is holding public hearings to assess the safety and public acceptability of the concept of deep geological disposal in granitic rock of the Canadian Shield, developed by Atomic Energy of Canada Limited.

The Canadian Environmental Assessment Agency held hearings in 1995 on the management of 110 million tonnes of Canada's uranium mine tailings (more than half the Canadian total) in Elliot Lake.

The outlook for the construction of new nuclear power plants in Canada is uncertain. However, most of the 22 existing nuclear power reactors, located at five sites in three provinces (Ontario, New Brunswick, and Quebec), are expected to remain in operation. As well, the production, mining, and processing of uranium in Canada are likely to continue because of the relatively high-grade uranium found in Canada, particularly in Saskatchewan.

This means that inventories of LLRW and NFW are bound to continue to increase over the foreseeable future. The inventory of LLRW (excluding mine and mill tailings) could rise by 33% between 1991 and 2025 (Table 11.21). The most pronounced rise in LLRW is expected to occur sometime after 2030, when commercial nuclear reactors are scheduled to be decommissioned. NFW will also increase when the fuel from the reactors is finally discharged.

Sustainable development perspective

Resource conservation and environmental stewardship
In the context of the sustainable production and consumption of energy, two issues are of particular relevance: resource conservation and environmental stewardship.

Excessive depletion of nonrenewable energy resources could compromise the ability of future generations to secure access to reasonably priced supplies of energy and constrain future economic growth. However, resource depletion is not viewed with the same alarm in the 1990s as it was in the 1970s. Instead, the debate has shifted from whether society is likely to run out of energy to whether the environmental impacts of energy production and use can be kept within the carrying capacity of the ecosystem.

Future energy resource extraction
Fossil fuels currently supply about 70% of Canadian primary energy demand and over 80% of world primary energy demand. One way of judging the abundance of fossil fuels is by comparing the total quantity of fossil fuels recoverable from existing, known reserves with total annual production. A reserve life index, consisting of recoverable oil reserves divided by annual production, can thus be calculated (Table 11.22).

At current production rates, Canadian known reserves of oil could last another 13 years, compared with 24 years for natural gas and 132 years for coal. These estimates refer to reserves that have been geologically proven to exist and that can be exploited economically at current prices and with existing technology.

Worldwide fossil fuel reserves are much larger: approximately 45 years for oil, 61 years for natural gas, and 232 years for coal. Again, these estimates refer to reserves that are currently known and that can be exploited at current prices with existing technology.

Occurrences of oil, natural gas, and coal in the Earth's crust, however, are many times larger than current estimates of known commercial reserves. In addition to reserves that are known and commercially viable at current prices and technology, there are known subeconomic deposits that could become viable with improvements in technology and/or higher prices. There are also known deposits still to be proven and further delineated by drilling, and there are still other deposits yet to be discovered.

Estimates by the National Energy Board suggest that ultimate (remaining) recover-

Table 11.20
Uranium mine and mill tailings, by region, 1992

Region	Waste quantity (Mt)	Area covered (ha)	Site status
Northwest Territories	1.0	34[a]	All sites inactive
Saskatchewan			
North of Lake Athabasca	10.6	109	All sites inactive
South of Lake Athabasca	9.2	225[b]	All sites active
Ontario			
Bancroft Area	6.4	51	All sites inactive
Elliot Lake Area–North	168.0	1 088	One active site
Elliot Lake Area–South	7.5	63	All sites inactive
Total	202.7	1 570	

[a] Estimated.
[b] The total area under management; not all of this area is currently used for tailings disposal.
Source: Statistics Canada (1994b).

Table 11.21
Inventories and accumulation rates of low-level radioactive wastes, by source

Source	1991 inventory (m^3)	2025 projected inventory (m^3)	Current accumulation rate (m^3/year)
Nuclear fuel cycle	38 540	210 580	5 060
Research and development[a]	86 680	168 620	2 410
Nonnuclear activities[b]	7 930	8 270	10
Historical activities	1 163 820	1 170 620	200
Decommissioning	1 820	170 600	800[c]
Total	1 298 790	1 728 690	8 480

[a] Includes radioisotope production.
[b] Activities not directly related to the processing of radioactive materials but that nevertheless produce low-level radioactive wastes (e.g., mineral processing and the combustion of coal).
[c] Does not include wastes from decommissioning of nuclear reactors used for commercial electricity production, as no decommissioning of these units is currently under way. Decommissioning of commercial nuclear reactors is expected to commence after 2015; this will account for most of the projected 2025 inventory of low-level radioactive wastes from decommissioning activities.
Source: Statistics Canada (1994b).

able fossil fuel resources are relatively abundant in Canada, particularly bitumen and coal. Known and geologically proven bitumen resources (found in Canada's oil sands) are estimated to contain 400 000 million cubic metres of oil, of which approximately 49 000 million cubic metres are estimated to be recoverable. At current production rates, this is equivalent to over 200 years of supply.

Total recoverable oil resources, conventional plus unconventional, are estimated to be sufficient to support the current rate of production for another 542 years. The equivalent estimates for natural gas and coal are 124 years and 1 208 years, respectively.

Environmental sustainability
Options for reducing environmental impacts from energy activities can be broadly categorized as follows:

- implementing pollution controls based on the use of add-on technologies;
- adopting "clean" energy technologies;
- improving energy efficiency;
- substituting more environmentally benign energy sources for fossil fuels; and
- shifting towards a "conserver" rather than a "consumer" society.

Add-on pollution control technologies, using end-of-pipe treatment of effluents or emissions to remove pollutants, have been the main technique used so far to control pollution. The use of scrubbers on power generating stations and the use of catalytic converters on cars are two prime examples.

The next most common approach has been the development and use of "clean" energy technologies. These use more efficient processes to decrease the production of pollutants. Examples are high-compression lean-burn engines and fluidized bed combustion systems for boilers.

Both of these approaches (add-on and "clean" technologies) require capital investments but can reduce operating costs and provide a good return on investment. Whereas pollution control technologies have contributed significantly to reducing energy-related pollution, clean energy technologies have not achieved their full economic potential to reduce energy consumption and production patterns either in Canada or abroad.

In some instances, improved efficiency and interfuel substitution are the only two options available for effectively reducing certain types of pollutants or for reducing a wide range of pollutants simultaneously. These options are particularly relevant to the problem of controlling energy-related greenhouse gases. According to some estimates, a 40–60% cut in carbon dioxide emissions would be required, on a worldwide basis, to stabilize carbon dioxide concentrations in the atmosphere at current levels (Intergovernmental Panel on Climate Change 1990; Government of Canada 1994). Improvements in energy efficiency can be relied on initially to stabilize the growth of carbon dioxide emissions, as can the substitution of low-carbon natural gas for high-carbon oil and coal. However, the deep cuts in emissions needed to stabilize the atmospheric concentration of carbon dioxide at present levels can come only from a much greater reliance on alternative and renewable energy sources and a change in social attitudes from a consumer to a conserver ethic.

Thus, even though present levels of fossil fuel consumption could be continued for many years before Canada's economically viable reserves were exhausted, to do so would be unsustainable because of the environmental impacts that would result. In fact, Canada will have to dramatically change its energy production and usage over the next few decades in order to be part of the global solution needed to avert the possibility of catastrophic climate change.

Table 11.22
Reserves and resources of nonrenewable energy, Canada and the world, 1992

		Reserves/ resources	Production	Reserve/resource life index[a] (years)
Reserves[b]				
Canada	Crude oil (m^3, millions)			
	Conventional	841	79.6	11
	Unconventional	485	20.8	23
	Total	1 326	100.4	13
	Natural gas (m^3, billions)	2 711	115.0	24
	Coal (t, millions)	8 623	65.3	132
World	Crude oil[c] (m^3, millions)	157 482	3 494.9	45
	Natural gas (m^3, billions)	124 024	2 041.7	61
	Coal (t, millions)	1 040 529	4 483.8	232
Resources[d]				
Canada	Crude oil (m^3, millions)			
	Conventional	6 174	79.6	78
	Unconventional	48 249	20.8	2 320
	Total	54 423	100.4	542
	Natural gas (m^3, billions)	14 304	115.0	124
	Coal (t, millions)	78 875	65.3	1 208

[a] Reserves or resources divided by current annual production.
[b] Resources that have been geologically proven to exist and are economically exploitable, given current prices and technology.
[c] Excludes unconventional crude oil.
[d] Remaining resources that are and may become recoverable or marketable, having regard to geological prospects and anticipated technology.

Source: British Petroleum (1992); National Energy Board (1994a, 1994b, 1994c).

Conclusion

Progress has been made in addressing threats to life support systems through the reduction of sulphur dioxide emissions: between 1970 and 1990, sulphur dioxide emissions related to energy use were cut by about 30%, largely as a result of the wider use of lower-sulphur fuels. Under the Canadian Acid Rain Control Program, national targets for aggregate sulphur dioxide emissions were met ahead of schedule.

Further reductions in fossil fuel-related emissions will be needed if Canada is to meet its emission reduction objectives for greenhouse gases, nitrogen oxides, and VOCs. As many atmospheric pollution problems transcend national boundaries, international cooperation is imperative if Canada and other nations are to meet the challenges of sustainable development.

Despite significant progress in controlling lead emissions, releases of poisonous and toxic substances such as benzene and metallic contaminants continue to be of concern. The federal government is attempting to reduce the benzene and heavy metal content of gasoline to more acceptable levels.

Although the number of suitable sites for hydroelectric power development is getting smaller, considerable undeveloped potential remains. Concerns about the environmental and social impacts, however, have resulted in rethinking the development of new, particularly megascale, hydroelectric power projects. For example, the Grande-Baleine (Great Whale) project in northern Quebec and the Kemano completion project in northeastern British Columbia have both been put on hold because of public concerns regarding their potential impact on environmental sustainability and on the society, economy, and health of the Aboriginal people living in these areas.

Even without the construction of new nuclear reactors, the inventory of both low-level radioactive waste and nuclear fuel wastes is set to rise. Although disposal methods for highly radioactive wastes are under study, no permanent disposal method has yet been approved, and it may take many more years, if not decades, to implement a permanent disposal system.

As noted in the "Environmental trends and issues" section, renewable energy sources are also not totally environmentally benign. They can contribute to air pollution and waste disposal problems, diminish the aesthetic appeal of the landscape, remove land from agricultural use, and destroy wildlife habitat. However, as their environmental impacts are often different from and less than those of conventional energy sources, their greater use would contribute to sustainability.

Significant progress has been made in controlling pollution from energy systems and thus in protecting both natural ecosystems and human health. Obviously, more remains to be done. New approaches and additional efforts will be required if Canada is to achieve the targets that Canadians have set for themselves.

Transportation

Introduction

Transportation is the lifeblood of Canada's economic and social community. It is both a critical element in our success as a trading nation and a vital service, providing the access and mobility demanded by modern society.

However, transportation also contributes significantly to environmental stresses, including consumption of nonrenewable natural resources and generation of wastes, emissions, and spills. These stresses contribute to air, ground, and water pollution and to climate change.

The effects of transportation on the environment can be represented as a stress–condition–response cycle, beginning with transportation demand and the environmental stresses created by transportation activities. The cycle is completed by society's responses to the environmental conditions resulting from these activities and stresses. These responses include changes in infrastructure (i.e., the roads, rails, airports, and other physical structures that form the foundation for transportation), technological advances, pricing adjustments, regulation, and transportation demand management. Each of these responses, in turn, modifies transportation demand and activities in a variety of ways.

Environmental stresses from the Canadian transportation sector range from local to global in scale. Oil and fuel spills, waste disposal problems, toxic chemical releases, carbon monoxide emissions, and pressure on land resources are largely local in impact, but the effects of ground-level ozone and acidic deposition extend to a regional level. Globally, transportation contributes to global warming and, to a lesser extent, to stratospheric ozone depletion (Sypher: Mueller International Inc. 1992).

Within the transportation sector, passenger rather than freight transportation is the greater contributor to environmental problems (except for oil and fuel spills and toxic chemical releases). This situation results largely from the high volume of trips, the greater total distance travelled annually, and the degree of congestion associated with passenger use. Similarly, because most of Canada's population is located in urban centres, urban rather than intercity or rural transportation plays a more significant role in influencing the level of energy consumption and adding to environmental stresses.

This component of the chapter traces these cause-and-effect relationships between transportation activity and environmental conditions. It first describes transportation as a basic part of the Canadian economy, in terms of the number of people it employs and its contribution to the country's economic output. It also relates some basic facts about transportation demand: how people and goods move today in Canada, and how they are likely to do so in the near future, if current trends continue.

It then reviews how demand for transportation activity, and the infrastructure built to satisfy that demand, affect the natural and social environment. The third section outlines recent progress in implementing more sustainable transportation systems and

practices. Because of its high volume and greater environmental impact, passenger transportation is analyzed in greater detail.

Transportation, the economy, and lifestyles

Transportation provides all economic sectors with access to resources, facilities, markets, and labour. Even while our economy evolves from a resource extraction and goods manufacturing base to a service and information base, our success as a trading nation continues to rely on an effective transportation system.

Socially, transportation relieves isolation and provides basic access to a wide variety of social, educational, and leisure activities. In 1992, there were 13.3 million passenger cars in operation in Canada — nearly one car for every two people, the highest rate of car ownership in the world next to the United States. In addition, there were 4.1 million other motor vehicles on Canadian roads (Statistics Canada 1994b and various years, Catalogue No. 53-219). As of 1990, urban public transportation services carried over 1.5 billion passengers, intercity buses transported nearly 17 million passengers, rail was used by 29 million passengers, over 36 million passengers travelled by air, and almost 34 million passengers used ferry services (Statistics Canada 1994b). Most Canadians enjoy and have come to depend on a high degree of mobility, although important equity issues continue to exist regarding the mobility needs of special groups: Canadians living in remote regions, the handicapped, the aged, the poor, and others who are among the approximately 25% of households that do not own a vehicle.

Because transportation services are used by every sector of the economy, and because transportation likewise draws on many goods and services, it is difficult to isolate accurately the role played by transportation in Canada's economy. As shown in Table 11.23, transportation accounted directly for approximately 3.5% of the GDP in 1992. On average, transportation tends to account for about 10% of the cost of a typical product or service, although transportation costs may range from 5% to 50% for any given item.

An average household spent 12.5% of its gross income on transportation in 1992, a proportion roughly equal to that spent on food (Statistics Canada 1993a, 1994b). This proportion of household expenditure on transportation has changed little since 1969. In 1991, Canada exported $141.7 billion worth of goods and services and imported $135.9 billion (Statistics Canada 1994f). This level of trade is very dependent on a reliable and cost-effective transportation system.

The provision of transportation services directly employs about 4% of the national workforce (Statistics Canada 1994b). This figure rises to 10% if one includes employment that supports the delivery of transportation services, such as vehicle and highway construction or automobile dealers and garages (Statistics Canada, various years, Catalogue No. 72-002). However, when other sectors that owe at least a part of their livelihood to transportation (e.g., public administrators, municipal police, fire and ambulance services, insurance companies, etc.) are considered, the pervasive role of transportation in the Canadian economy becomes more evident.

Transportation demand and supply

The transportation system moves both people and goods. These two spheres, however, are distinctly different in terms of activity and technology.

Passenger transportation

Table 11.24 shows how the different modes of transport contributed to moving people in 1992 in terms of the number of passenger–kilometres travelled (see Box 11.18).

Figure 11.46 illustrates the estimated levels of Canadian transportation activity between 1950 and 1994 as calculated on an interim basis (Environment Canada 1996d). Passenger travel has grown steadily and dramatically: between 1950 and 1994, passenger travel increased more than fivefold, while Canada's GDP increased fourfold and its population only doubled.

The automobile's share of total passenger travel has been fairly steady between 1950 and 1994, whereas rail has lost 90% of its share of passenger transportation activity, largely to air travel. Although bus travel has increased in absolute terms, it has lost two-thirds of its 1950 share, partly owing to increased air and automobile travel between cities, but largely because of the greater use of cars instead of urban transit for travel within cities. Air travel's share has grown 14 times during the same period, partly by displacing travel by other modes,

Table 11.23

Share of transportation in gross domestic product and employment, 1961–1992

Year	GDP at factor cost (1986$, millions)			Employment (no. of people, 000s)		
	Total	Transportation	Transportation as % of total	Total	Transportation	Transportation as % of total
1961	156 428	6 065	3.9	–	–	–
1971	267 060	10 574	4.0	–	–	–
1981	397 090	14 536	3.7	–	–	–
1982	382 575	13 615	3.6	–	–	–
1984	418 717	16 661	4.0	9 036	440	4.9
1986	451 839	17 493	3.9	9 626	437	4.5
1988	492 587	19 297	3.9	10 329	440	4.3
1990	504 787	18 636	3.7	10 796	466	4.3
1992	503 638	17 798	3.5	9 952	421	4.2

Note: The transportation sector includes air, water, rail, and truck transport, urban transit systems, taxicab industries, services incidental to transportation, as well as bridge and highway maintenance industries

Source: Adapted from Statistics Canada (1994b and various years, Catalogue Nos. 15-001 and 72-002)

but mostly through growth in long-distance international travel, where air has virtually no competition.

The decline of urban transit is closely mirrored by the rise in automobile ownership, as Figure 11.47 shows. In 1950, when only about one person in seven owned an automobile, the average person took 250 trips throughout the year on transit, a ridership level now seen only in Canada's two largest cities. By 1990, there were nearly half as many automobiles as people in Canada, and the average Canadian with access to transit service took only about 100 rides on transit. The inverse relationship between auto ownership and transit ridership was briefly interrupted in the 1970s and early 1980s, owing largely to the effects of the two "oil crisis" episodes and the startup of some major new rapid transit systems. However, since about 1986, transit ridership per capita has declined moderately but continuously.

International comparisons show that Canadians tend to travel more than residents of other G-7 countries with a comparable standard of living (Table 11.25). Measured on the basis of passenger–kilometres per person, Canadians in 1988, on average, travelled 9.4% farther by auto, 25.2% farther by air, and 3.5% farther by all modes of passenger transportation (the last figure reflecting lower levels of travel by bus, rail, and ferry) than their counterparts in the other six G-7 countries. Only residents of the United States, on average, travel greater distances than Canadians (Royal Commission on National Passenger Transportation 1992). Although some of this difference, particularly for air travel, might be explained by the larger physical size of Canada, the largest proportion of the travel occurs within cities or the urban region surrounding the major cities, suggesting that low-density, spread-out suburban development has also been a major factor.

If current trends and policies continue, Canadian passenger travel will likely continue to increase faster than population

Table 11.24
Canadian passenger travel, 1992

Mode	Passenger–kilometres (billions)	%
Car	355.6	82.0
Bus (intercity bus and urban public transit)	14.5	3.3
Rail	1.3	0.3
Air	62.5	14.4
Total	433.9	100.0

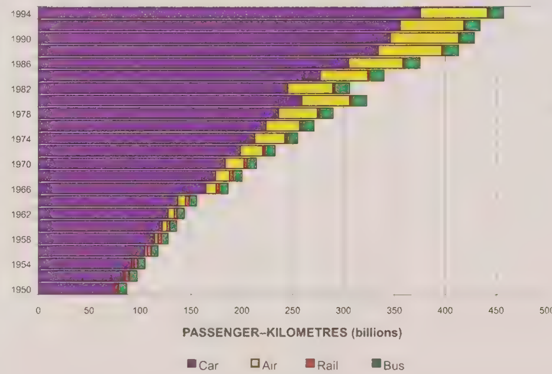
Notes: Passenger transportation includes both intercity travel and travel within the city. Calculations are based on the data and approach derived from Royal Commission on National Passenger Transportation (1992); and data from Canadian Urban Transit Association (various years); Statistics Canada (various years, Catalogue Nos. 51-501 and 52-216). Annual vehicle–kilometres for automobiles were derived from the Transportation Energy Demand Model, Natural Resources Canada. Percentages do not total to 100 owing to rounding.

Source: Adapted from Environment Canada (1995d, 1996d).

Box 11.18
Measuring travel

A passenger–kilometre is a standard unit for measuring travel, as it accounts for both the number of people travelling and the distances travelled. Another common unit of measure in transportation is the vehicle–kilometre, which accounts for the number of vehicles travelling and the distance travelled. For example, if 10 people wish to travel a distance of 20 km, this represents 200 passenger–kilometres of travel. If all 10 people are transported together (e.g., by bus), this would represent 20 vehicle–kilometres of travel. If, on the other hand, each person drives separately in an automobile, this would represent 200 vehicle–kilometres of travel. Typically, freight is measured in tonne–kilometres.

Figure 11.46
Canadian passenger transportation activity, 1950–1994



	% of Canadian passenger travel			
Year	Car	Air	Rail	Bus
1950	85	1	4	9
1970	86	9	1	4
1990	81	16	<1	3
1994	82	14	<1	3

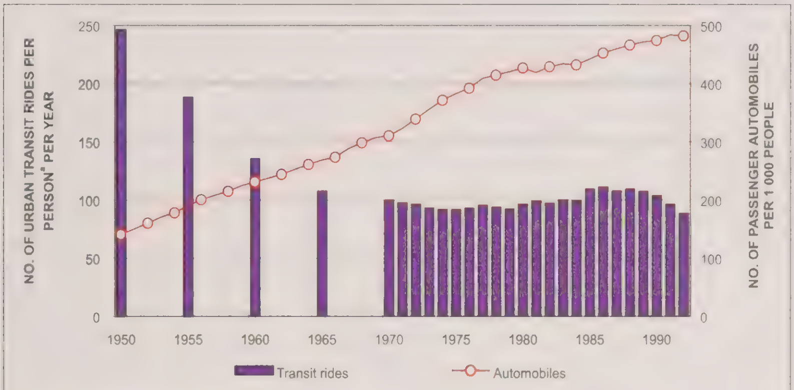
Note: Passenger transportation includes both intercity travel and travel within the city. Calculations are based on the data and approach derived from Royal Commission on National Passenger Transportation (1992); and data from Canadian Urban Transit Association (various years); Statistics Canada (various years, Catalogue Nos. 51-501 and 52-216). Annual vehicle–kilometres for automobiles were derived from the Transportation Energy Demand Model, Natural Resources Canada.
Percentages do not total to 100 owing to rounding.

Source: Adapted from Environment Canada (1995d, 1996d).

growth. That is mainly because people will own more automobiles and be travelling more as a result of relatively low prices for vehicles and energy, higher household incomes, smaller-sized households with a greater number of mobile adults, and more women entering the workforce. Also, intercity rail and bus travel and urban public transportation will likely continue to decline, and air and automobile travel will more than make up the difference.

The demand for passenger transportation is affected by many factors but is essentially dictated by both the necessity and the desire for individuals to move between places so as to participate in a variety of social and economic activities. Demographics, household incomes, labour force participation rates, the spatial arrangement of land uses, and the flexibility, convenience, and cost of the available modes and routes also play a significant role in shaping passenger transportation activity levels and patterns.

Figure 11.47
Auto ownership and urban transit usage, 1950–1992



[a] Persons with access to transit service.

Sources: Statistics Canada (various years, Catalogue No. 53-219); Canadian Urban Transit Association (various years).

Table 11.25
Canadian passenger travel in comparison with other G-7 countries, 1988

Country	Passenger–kilometres per person: Auto	Air	Total
Canada	13 181	2 084	15 825
United States	18 775	2 787	21 942
Japan	4 528	684	9 105
France	9 913	859	12 687
West Germany	8 971	554	11 055
Italy	8 094	348	10 548
United Kingdom	8 254	2 068	11 636
Average of 6 countries other than Canada	12 051	1 664	15 287
	Canada compared with average of other 6 countries		
Difference (passenger–kilometres per person)	+ 1 130	- 420	+ 538
Difference (%)	+ 9.4	- 25.2	+ 3.5

Notes: Urban, intercity, and international passenger travel are included. Total passenger travel includes transit, bus, rail, and ferry travel in addition to auto and air travel. The "average of 6 countries other than Canada" is weighted on the basis of the total population of each country.

Source: Royal Commission on National Passenger Transportation (1992).

Freight transportation

The four major modes of transport used to move goods in Canada are rail, truck, marine, and air. Table 11.26 shows how the various modes were used to move goods in Canada in 1993 in terms of tonne–kilometres of cargo delivered. Although the rail freight mode dominates, the share of the market held by trucking has been steadily increasing for the past 30 years, and this trend shows little sign of slowing (Statistics Canada 1990). It should also be noted that freight moved by trucking is understated. Estimates of minor-firm and private truck haulage by Statistics Canada (1991) suggest that the total tonne–kilometres of cargo moved by truck is likely double the amount carried by for-hire firms only, and the average percent share of freight moved by trucks is likely over 30%.

The factors affecting the demand for freight transportation are similar to those affecting passenger transportation. However, the process for freight transportation is a little simpler, as the choice of mode is usually based only on economic factors that affect a company's bottom line, such as time, cost, reliability, and flexibility. Lately, shippers have been placing greater emphasis on reliability and flexibility. Many companies employ a "just-in-time" system in which they maintain small inventories of supplies and consequently rely heavily on timely deliveries, usually by truck.

Transportation — its effect on the environment and society

This section provides an overview of the environmental issues and challenges currently facing Canadian transportation.

Transportation and the environment

Transportation can be imagined as a "black box," similar to a component in an electronic circuit, receiving inputs from various parts of the system and transferring them as outputs to other parts. In this case, the "black box" draws certain resources from the natural environment

and inputs from other sectors of human activity, processes them, and produces some useful services and not so useful environmental stresses, as illustrated in Figure 11.48. Transportation directly or indirectly affects all environmental media and ecosystem components.

Land consumption

On the input side, transportation affects the environment directly by using land. Transportation systems require a significant amount of land, and land used in transportation is rarely usable for other purposes. In 1991, Canada's road network (two-lane equivalent) spanned 888 898 km — a length more than 23 times greater than the distance around the globe (Transportation Association of Canada 1991).

In the rural areas of Canada, transportation systems use up farmland, forests, and wetlands. They also fragment woodlots and other wildlife habitats into smaller, less diverse areas, causing a serious threat to biological diversity. In Canadian urban areas today, automobile-oriented transportation patterns facilitate low-density suburban development on the urban fringe and far-flung residential estate development in the countryside beyond. Extensive tracts of single detached homes with large lots along curvilinear streets act as a deterrent to the efficient provision of urban public transit, to the widespread use of cycling as a means of commuting, and to walking to schools, shops, or work. In the inner city, transportation facilities use lands that could have been used for housing, places of work, social and recreational services, or people-oriented parks and open space. As much as 42% of downtown land may be occupied by roads, bridges, garages, and parking lots (Lea and Associates Ltd. 1975; see Chapter 12 for more detail).

Material consumption

Transportation also draws on the natural environment indirectly by using products from the energy, minerals, and manufacturing sectors, which draw their raw materials, such as nonrenewable mineral resources, from the environment. In 1989, for example, the average motor vehicle (car, van, or station wagon) consisted of 1 428 kg of metals, plastics, and other materials (Government of Canada 1991).

In terms of sustainable development, the prospects for running out of most mineral resources nevertheless seem remote. Also, much of the material used in transportation can be recycled; for example, about 75% of the materials in scrap road vehicles, particularly metallic components, can be recycled (Siuru 1991). As well as extending the life span of nonrenewable resources, metal recycling requires 50–74% less energy for production and releases 86% less air pollution, 76% less water contamination, and 97% less solid waste than metal production from ores (Government of Canada 1991). Recycling potential is becoming more important with increasing concern about the social and environmental consequences of resource extraction and the possibility that the costs of primary production might increase as high-grade sources are depleted (see the "Minerals, metals, and mining" component).

Energy

From a sustainability point of view, by far the most worrisome resource used by transportation is energy. In 1994, transportation accounted for 30% of total energy end use in Canada (Statistics Canada 1994d). The transportation industry derives 97% of its energy from refined petroleum products. In 1992, retail pump sales of gasoline accounted for 67% of transportation petroleum product sales, whereas diesel and gasoline sales to the trucking and transit industries accounted for 12%, air travel consumed 9%, and rail and water-based transport accounted for 6% and 7% of sales, respectively (Statistics Canada, various years, Catalogue No. 57-003).

Since the Second World War, virtually every transportation mode has made impressive gains in fuel efficiency, and more gains are expected in the future. For example, between 1974 and 1994, the average Canadian passenger vehicle (in-use automobile fleet) improved 39% in terms of energy used per kilometre of travel (Environment Canada 1996d). However, these changes have been evolutionary rather than revolutionary; the basic technology of transport has not changed appreciably in the past 40 years. The nearly 50% gain in new automobile fuel efficiency — a decrease from 16.5 to 8.4 L per 100 km — that occurred from 1973 to 1982, during the "energy crisis," has been followed by a period of gradual improvement, from 8.4 to 8.0 L per 100 km, from 1983 to 1993 (Transport Canada, various years; Environment Canada 1995d). Indeed, the new automobile fuel efficiency levels have virtually plateaued since 1988.

There are signs that the evolutionary gains in fuel efficiency are reaching their limits

Table 11.26

Freight movement by Canadian carriers, 1993

Mode	Tonne–kilometres (millions)	%
Truck[a]	83 751	21.6
Rail[b]	256 338	66.0
Marine[c]	46 854	12.0
Air	1 646	0.4
Total	388 589	100.0

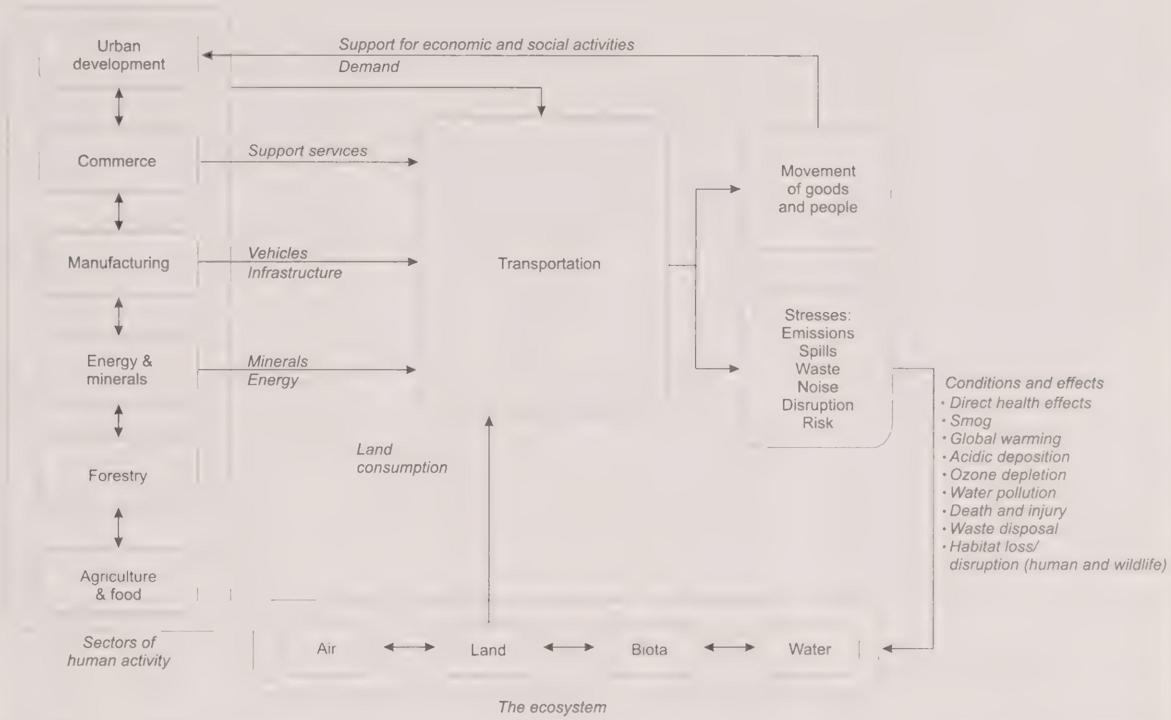
[a] Major "for hire" trucking firms on intercity movements only. This encompasses approximately 50% of all truck freight. If other private trucking freight is included, truck tonne–kilometres could nearly double, and the percent share of freight would rise to over 30%. See Statistics Canada (1991), Table 3.1.2.9.

[b] Domestic rail freight movement only.

[c] Domestic shipping only.

Sources: Statistics Canada (1994g, 1994h, 1995c, 1995d); B. Mitchell, National Accounts and Environment Division, Statistics Canada, personal communication.

Figure 11.48
The transportation "black box"



Source: IBI Group (1991).

and being offset by increases in vehicle registrations and the higher average distance each vehicle is driven annually. Without widely adopted revolutionary changes (like those proposed by the recent Partnership for a New Generation Vehicle initiative in the United States, which aims to develop vehicles that are three times more fuel efficient than current vehicles), the technology of transport will continue to improve, but at a decreasing rate.

The technology of choice in transportation continues to be the gasoline-fuelled internal combustion engine. However, alternative fuels and engine technologies have been under development or use for many years. They generally fall into three categories: other petroleum-based fuels (natural gas, propane), alcohol fuels (methanol, ethanol), and electricity and hydrogen. Alternative petroleum fuels have the advantage that they are relatively more abundant in Canada than oil, although ultimately the reserves are neither infinite nor renewable. They are also cleaner fuels, producing smaller amounts of some pollutants and comparable amounts of others. Alcohol fuels such as ethanol and methanol have the added advantage that they can be produced from sources other than petroleum, including some that are renewable and therefore sustainable over the long term, such as wood chip residue from forestry and methane gas from landfills. However, concerns exist about the true sustainability of producing ethanol from grain, its main feedstock in the near term, given the amount of land required to produce significant quantities, the potential of soil degradation, and the energy input required in the form of fertilizer. Nevertheless, alcohol fuels are cleaner than gasoline and diesel with respect to some pollutants and no worse with respect to others.

Today, there is a great deal of interest in the potential of electricity and hydrogen as alternative transportation fuels (ATFs). Hydrogen- or electrically powered vehicles are cleaner than their oil-fuelled counterparts, but their net effect on environmental sustainability is unclear because of other problems that may arise from the production of the hydrogen and electricity. If they are produced from renewable sources, then these technologies are sustainable. However, if their energy is derived from unsustainable sources or feedstocks such as coal or sources such as nuclear plants, which

involve a host of other risks in their operation and development, then these technologies may simply exchange some environmental and energy problems for others. Table 11.27 shows emission of greenhouse gases relative to petroleum for various alternative fuels and feedstocks.

Alcohol and alternative fuels are used routinely now, particularly by vehicle fleets, although their use relative to gasoline and diesel fuel is extremely low, supplying less than 2% of road transport demand in 1991 (Natural Resources Canada 1993). The market share of ATF vehicles is projected to exceed 4% of Canadian road transport by 2010, a small but growing proportion.

Overall, Natural Resources Canada (1994c) has projected that road transportation energy demand in Canada will be up to 19% higher than 1990 by 2010 and 37% higher than 1990 by 2020 (Reference Scenario). These projections reflect moderate growth in the amount of travel and a relatively low rate of improvement in new car fuel efficiency of 0.4% annually from 1990 to 2020.

On the output side of the "black box," transportation produces a variety of benefits as well as a large number of environmental pollutants and stresses. These stresses can be grouped into three categories: emissions, spills, and solid waste.

Air emissions

First and foremost are emissions. Except for such modes as walking, bicycling, and sailing, transportation generally emits pollutants into the air. What pollutants are emitted? What are their effects? How do the transportation modes differ in their emissions, and how does transportation compare with other sources of air pollution? These questions are addressed below.

Table 11.28 summarizes the air pollutants emitted by transportation and the environmental problems to which each pollutant contributes. The table also indicates whether transportation is a major contributor of each pollutant compared with other human-related sources.

Transportation is responsible for significant releases of carbon monoxide, VOCs, nitrogen oxides, carbon dioxide, and benzene. In addition to being significant pollutants in their own right, VOCs and nitrogen oxides react in sunlight to produce a third pollutant — ground-level ozone in the smog. Transportation also contributes sulphur oxides (SOx), particulates, and chlorofluorocarbons (CFCs), the latter from air conditioner leaks and blowing agents used in vehicle manufacturing (although these uses of CFCs were phased out in new vehicles in 1995).

Air emissions from transportation are linked directly to health problems in the form of bronchial and lung disorders, urban smog, with its attendant damage to vegetation and human health, global warming, acidic deposition, and ozone depletion (see Chapter 10).

How much does each of the transportation modes contribute to emissions into the air? The sheer number of vehicle-kilometres travelled by automobiles compared with all other modes, passenger and freight combined, make them easily the largest contributor to transportation air pollution. On the basis of emission levels per passenger, the car with a single occupant emits the highest levels of nitrogen oxides, VOCs, and carbon monoxide, but levels are significantly reduced by car pooling, van pooling, and public transit (Table 11.29).

From the standpoint of air pollution and energy consumption, a transportation system's sustainability is shown most readily by its emissions of carbon dioxide, which is the leading agent in global warming. It is a direct product of fossil fuel combustion and is therefore also linked to the system's consumption of nonrenewable resources. Although other factors come into play, fuel use also affects emissions of directly harmful pollutants, such as nitrogen oxides, carbon monoxide, and VOCs.

Since 1950, carbon dioxide emissions in Canada from transportation are estimated to have increased by over 500% according to interim calculations, peaking in 1980 and remaining fairly stable between 1984 and 1992, as fuel efficiency improvements tended to lower emissions but were offset by increased automobile ownership and greater average annual distances travelled (Fig. 11.49). From 1992 to 1994, Canadian carbon dioxide emissions from transportation rose moderately. Over the 1950–1994 period, Canada's population increased by

Table 11.27
Emissions of greenhouse gases from alternative fuels, including production, distribution, and end use of fuel

Fuel or feedstock	% change in greenhouse gas emissions/km relative to petroleum
Hydrogen or electricity (nonfossil power)	–100
Methanol/CNG[a]/LNG[b] from biomass	–100
Doubled fleet efficiency, gasoline and diesel	–50
CNG from natural gas	–19
LNG from natural gas	–15
Methanol from natural gas	–3
Electric vehicles: current power generation mix	–1
Gasoline and diesel from crude oil	No change
Methanol from coal	+98
Liquid hydrogen from coal[c]	+143

[a] Compressed natural gas.
[b] Liquefied natural gas.
[c] Using coal-based energy in the production process.

Source: Sperling and Deluchi (1989).

100% (Environment Canada 1996d). The transportation system produces 27–32% of Canada's total carbon dioxide emissions (Environment Canada 1995d; Government of Canada 1995a).

Although nearly all modes of transportation produce carbon dioxide, there are substantial differences among them. The air and automobile modes are the largest emitters, not surprisingly, given their dominance of passenger travel. However, as Figure 11.50 shows, even on a per passenger–kilometre basis, automobile and air rate rather poorly compared with rail or bus. This relationship also holds true for other pollutants, such as nitrogen oxides, VOCs, and carbon monoxide.

With the exception of carbon dioxide, which has been relatively stable over the past decade, the pollutants emitted per vehicle–kilometre by each type of vehicle have decreased in the past 20 years, owing to improvements in emission control technology. Further (but smaller) improvements are expected. For example, the average new car in 1990 produced only 24% of the nitrogen oxides, 4% of the VOCs, and 4% of the carbon monoxide of a new car of the early 1970s (Environment Canada 1993b). However, there are signs that the rate of improvement in emission control is slowing and that we may be reaching the limits of technological fixes. Also, improvements on a vehicle–kilometre basis will be reduced and perhaps wiped out completely if the total number of vehicle–kilometres travelled continues to increase. Consumer selection of new vehicles is also a concern, as Canadians are switching away from small cars and light trucks to larger ones. The average fuel consumption of new vehicles in Canada (fleet average) has been relatively stable since 1988 and has actually risen recently. In addition, vehicle maintenance and the age of the in-use vehicle fleet are factors. One study has suggested that nearly 50% of total emissions may be produced by only 10% of all vehicles (IBI Group 1991). Nevertheless, the most recent forecasts from Environment Canada (1996e) indicate that, by 2005, transport-related emissions of nitrogen oxides and VOCs will be 13.2% and 27.4%, respectively, below their 1990 levels. These forecasted changes start to plateau by 2005, however, and rise slightly by 2010.

Whether carbon dioxide emissions in the remaining years of this decade stabilize, decline, or rise relative to 1990 will depend largely on two factors — the rates at which automobile and air travel continue to grow and the rate at which automobile fleet fuel efficiency continues to increase as older, less efficient cars are retired.

Table 11.28

Air emissions from transportation sources and environmental issues

<table>
<tr><th colspan="2" rowspan="2">Air pollutant</th><th colspan="10">Air pollutant contributes to</th><th rowspan="2">Is transportation a major contributor? (% emissions from transportation)</th></tr>
<tr><th colspan="2">Direct health problems</th><th colspan="2">Smog</th><th colspan="2">Greenhouse effect</th><th colspan="2">Acidic deposition</th><th colspan="2">Ozone depletion</th></tr>
<tr><td colspan="2">Carbon monoxide (CO)</td><td colspan="2">YES</td><td colspan="2">NO</td><td colspan="2">NO</td><td colspan="2">NO</td><td colspan="2">NO</td><td>YES; 60% of CO from human sources originates from transportation</td></tr>
<tr><td>Volatile organic compounds (VOCs)</td><td rowspan="2">Ozone (O_3)</td><td>YES</td><td rowspan="2">YES</td><td>YES</td><td rowspan="2">YES</td><td>NO</td><td rowspan="2">YES</td><td>NO</td><td rowspan="2">NO</td><td>NO</td><td rowspan="2">NO</td><td>YES; 40% of VOCs from human sources originates from transportation</td></tr>
<tr><td>Nitrogen oxides (NOx)</td><td>YES</td><td>YES</td><td>YES</td><td>YES</td><td>NO</td><td>YES; 60% of NOx from human sources originates from transportation</td></tr>
<tr><td colspan="2">Carbon dioxide (CO_2)</td><td colspan="2">NO</td><td colspan="2">NO</td><td colspan="2">YES</td><td colspan="2">NO</td><td colspan="2">NO</td><td>YES; 27% of CO_2 from human sources originates from transportation</td></tr>
<tr><td colspan="2">Sulphur oxides (SOx)</td><td colspan="2">YES</td><td colspan="2">NO</td><td colspan="2">NO</td><td colspan="2">YES</td><td colspan="2">NO</td><td>NO; minor source (2.2% of emissions)</td></tr>
<tr><td colspan="2">Chlorofluorocarbons (CFCs)</td><td colspan="2">NO</td><td colspan="2">NO</td><td colspan="2">YES</td><td colspan="2">NO</td><td colspan="2">YES</td><td>YES; 25% from motor vehicle air conditioners, but slowly declining with CFC phaseout</td></tr>
<tr><td colspan="2">Particulates (diesel)</td><td colspan="2">YES</td><td colspan="2">YES</td><td colspan="2">NO</td><td colspan="2">NO</td><td colspan="2">NO</td><td>NO; minor source (1.3% of emissions)</td></tr>
</table>

Source: Adapted from Ontario Ministry of Energy and Ontario Ministry of Transportation (1991).

Spills onto land and water

A second category of environmental impact of transportation can be referred to as "spills." Spills include the relatively infrequent but sometimes catastrophic accidental discharge of hazardous materials during transport, including, ironically, spills of oil used to fuel transportation in the first place. Between 1985 and 1990, an average of 7.9 million litres of motor gasoline and 16.2 million litres of crude oil per year were reported as spilled in Canada during extraction, transportation, refining, storage, and delivery (NATES 1992). Disasters like the *Nestucca* (1988) and the *Exxon Valdez* (1989) oil spills on the west coast of North America and near-disasters like the Mississauga, Ontario, train derailment (1979) serve as reminders that in achieving an environmentally sustainable transportation system, the transportation of hazardous materials cannot be overlooked.

Spills also include the deposition and runoff of toxic material from vehicles themselves. It is estimated that the amount of oil leaked from motor vehicles and washed into lakes, rivers, and groundwater is six times the annual volume of oil spills. Runoff of other toxic materials, most noticeably deicing salt, and their effects on groundwater quality are also a significant concern (Transportation Association of Canada 1994a).

Solid waste

Another category of transportation-related stress is solid waste associated with old vehicles and the construction of transportation facilities. This issue is often overlooked, because it is viewed as a "solid waste" problem rather than a "transportation" problem. Many metallic components of vehicles are recycled or reused, but nonmetallic items such as plastics and rubber tires pose greater difficulties. "Design for recycling" has been receiving increasing attention as a solution to these problems. The idea is that manufacturers should design recyclability into the vehicle from the outset by selecting materials that can be recycled and by making vehicles easier to dismantle (Environment Canada 1993b). Recycling of construction and demolition waste from road and bridge building — notably asphalt and concrete, the recycling of which was already at significant levels by the mid-1980s — increased further between 1988 and 1992 (Senes Consultants Ltd. and Franklin Associates Ltd. 1995; see Chapter 12).

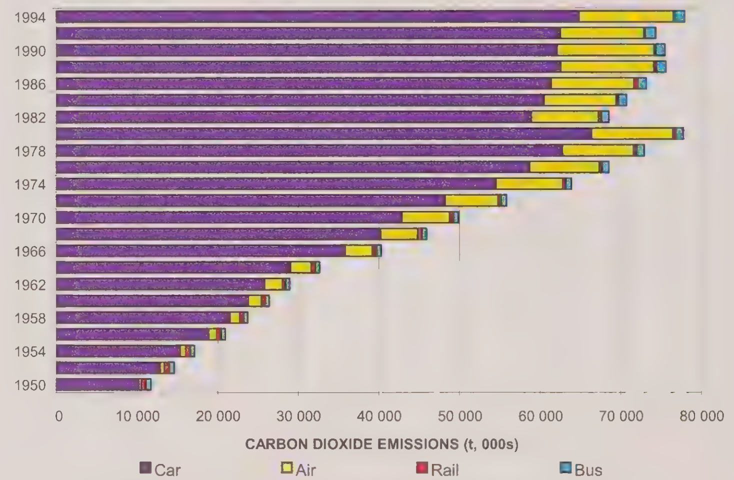
Table 11.29
A comparison of emissions per person, by transportation mode

Transportation mode	NOx	VOCs	CO
Light rail	43	0.2	2
Transit bus	95	12	189
Van pool	24	22	150
Car pool	43	43	311
Single-occupant car	128	130	934

Notes: Emissions in g/person-100 km. These are transportation modes typically used for urban commuting.

Source: Environment Canada (1993b); modified from Lowe (1990).

Figure 11.49
Carbon dioxide emissions from passenger transportation, 1950–1994



Notes: Calculations based on information derived from Royal Commission on National Passenger Transportation (1992); Canadian Urban Transit Association (various years); Statistics Canada (various years, Catalogue Nos. 51-501, 52-216, 53-215, and 57-003). Average automobile fuel efficiency derived from the Transportation Energy Demand Model, Natural Resources Canada. Carbon dioxide emission conversion factors derived from Jaques (1992).

Source: Adapted from Environment Canada (1995d, 1996d).

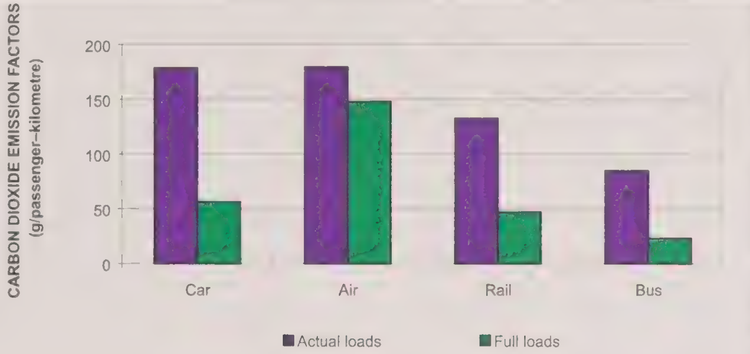
Transportation and society

In addition to its impacts on the physical environment, transportation also places stress directly on the social environment, most notably in the forms of noise, community disruption, and risk of accidents.

Noise

Nearly all transportation modes generate noise levels that can be objectionable. In urban areas, transportation activity dominates the "aural landscape." The effects of transportation noise include annoyance and stress due to interference with conversation, leisure, or sleep, decreased efficiency and proficiency in both physical and mental tasks, and potential or actual hearing loss.

Figure 11.50
Carbon dioxide per-unit emission factors, 1990



Note: Calculations are based on information derived from Royal Commission on National Passenger Transportation (1992); Canadian Urban Transit Association (various years); Jaques (1992); Statistics Canada (various years, Catalogue Nos. 51-501, 52-216, and 53-215).

Source: Environment Canada (1995d).

Community disruption
In the country, roads and railways alter the appearance of the rural landscape and can disrupt rural communities or wildlife migration patterns. In the city, highways, rail lines, airports, and seaports can disrupt communities and sever neighbourhood connections, adding to urban blight, creating "people-free" areas, and imposing a barrier to social interaction by those who do not own automobiles.

Risk of accidents
Transportation accidents are a major cause of injury and premature death in our society. Here again there are significant differences between the various passenger modes. In terms of accidents per passenger–kilometre, the automobile is significantly less safe than other forms of passenger transport, which are generally comparable in terms of safety. The relative safety of the freight modes is less clear; trucks are involved in a relatively large number of small incidents, whereas trains and ships are involved in fewer but larger incidents (Sypher: Mueller International Inc. 1992).

Towards sustainable transportation

The report of the World Commission on Environment and Development (1987) defined sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." In applying this concept to transportation, two questions come to mind:

- How does transportation contribute to meeting the needs of the present?
- How does transportation compromise the ability of future generations to meet their own needs?

In addressing the first question, the first thing to realize is that transportation is a derived demand. People generally travel to meet other needs and aspirations. Transportation itself is not an essential human need, but, because it can be basic to the satisfaction of other needs, it is often considered an essential need itself. However, if people can find easier or cheaper ways of meeting their needs without travelling or moving goods (e.g., through telecommunications), they will likely do so.

Regarding the second question, the basic concept of sustainability is that each generation bequeaths to its successor resources (e.g., farmland and topsoil, energy sources, minerals) and environmental quality (e.g., pure water, clean air) that are undiminished and, if possible, enhanced.

As noted previously, transportation poses problems to sustainability, in terms of both nonrenewable resource consumption and degradation of environmental quality.

What, then, would constitute a sustainable transportation system? Recognizing that transportation is a derived demand, environmental quality could, in theory, be best maintained if all need for a transportation system were removed. As it is impossible to meet all human needs and aspirations in this way, a "real-world" solution is a transportation system that, to the greatest extent possible, uses only renewable resources and does not contribute to environmental degradation.

Although zero transportation is neither attainable nor desirable, given the economic, social, and intellectual benefits of travel, the concept should always be kept in mind when seeking ways to improve the environmental sustainability of transportation systems. In addition to questioning how people and goods can be moved more cleanly and efficiently, one should always consider why the goods and people are moving in the first place and whether there are ways of meeting those needs directly in a more sustainable way without the need to travel or with shorter trips or less reliance on the automobile.

The concept of sustainability embraces many aspects, and one must realize that any given initiative may not necessarily deal equitably with all aspects. For example, it is possible to conceive of technological advances in transportation that would achieve zero emission of pollutants and would use renewable energy sources. One such approach would be to use engines that burn hydrogen, as the combustion of hydrogen produces only water vapour. If a relatively low-cost commercial system could be developed to create hydrogen (e.g., from water) using solar energy, this would be a fully renewable energy source and also a nonpolluting one.

However, such a technological advance would be only a partial solution, as the type of transportation system on which our country relies has significant impacts on the ecosystem beyond energy usage

and emissions. In other words, continuing automobile usage, even with nonpolluting technologies and using only renewable resources, would still tend to separate land uses, use up farmland and natural areas, degrade the quality of rural areas, and diminish the value of urban neighbourhoods and streetscapes as "people places."

As a basis for discussing potential sustainability initiatives, it is useful to consider a number of key categories and related measures of sustainability. Table 11.30 lists seven major types and several examples of technological and behavioural initiatives that can improve sustainability by:

- reducing the need for and amount of vehicular transportation;
- increasing the use of cleaner modes of transportation; and
- improving the environmental performance of all modes of transportation.

The column headings of Table 11.30 summarize 14 ways of measuring whether urban transportation is more sustainable, highlighting the areas of vehicular travel effort, conservation of resources, environmental quality, economic efficiency, quality of life, and lifestyle choices as significant aspects of sustainability. Although the measures and initiatives shown in the table relate specifically to urban travel, many of them are applicable to other aspects of passenger transportation.

The entries in the various cells of the table provide an indication of the anticipated impact of each initiative in helping to achieve more sustainable transportation, defined in terms of the table's 14 measures of more sustainable urban travel. They are presented to stimulate thinking and discussion in this area and to provide a context for the examples of actual Canadian initiatives given below.

Transportation infrastructure
The term "transportation infrastructure" refers to the permanent physical facilities required for the movement of people, freight, and vehicles. It includes such diverse facilities as streets, bridges, rights-of-way, rapid transit lines, freight terminals, pedestrian and bicycle ways, signal lights and crosswalks, parking spaces, reserved lanes, ports, rail lines, airports, and ferry and freight terminals. Many transportation infrastructure initiatives currently under way in Canada reflect the intention to achieve more sustainable transportation.

Government priorities and fiscal restraint have effectively curtailed the expansion of rapid transit infrastructure in Canadian cities in recent years. However, virtually all major cities have stated their desire to expand and/or improve their rapid transit networks. In contrast, there are relatively few plans to expand the highway network significantly, and there are indications that Canada's intercity system of rail lines, ports, and possibly airports will shrink in the future.

In addition to specific infrastructure projects, the transportation planning process itself has undergone a transformation in Canada. Life cycle management approaches are being introduced. The federal government and most provincial governments have enacted environmental impact assessment (EIA) legislation to introduce environmental concerns formally into the planning and design of transportation infrastructure projects (Transportation Association of Canada 1994b). The best of the Canadian processes are noted for their broad definition of the environment and their consideration of environmental values alongside, rather than after, traditional project criteria.

Ecosystem-based planning, a logical extension of EIA principles, has also been employed recently in transportation planning. The ecological planning approach articulated by the Royal Commission on the Future of the Toronto Waterfront (Barrett and Davies 1991) has aided it in assessing the benefits and costs of replacing part of a major elevated expressway in Toronto's central waterfront area with a combination of urban streets plus greatly improved commuter rail and transit services and related land use and urban design changes. Such changes include more downtown housing to help moderate the growth in long commuting trips from suburban areas, many of which are still by automobile.

Demand management
All initiatives discussed in this section can influence transportation demand, and all may be referred to as demand management practices. However, as applied here, the term refers specifically to practices, primarily employed within an urban area, that provide direct incentives for individuals to travel in off-peak times and to less congested destinations where possible, to use an alternative mode, to make shorter trips, to combine trip purposes and share vehicle use with others, and, in general, to use existing transportation infrastructure and vehicles more efficiently. Demand management practices encompass parking price management, alternative work schedules, ride sharing, high-occupancy vehicle lanes, telecommuting, distance learning, and direct pricing or tolling for the use of roads, including congestion or peak-load pricing.

Canadians have some experience with all of the above methods. Although interest in some of these practices waned in the mid-1980s with the stabilization of oil prices, interest has revived in recent years owing to environmental, energy, financial, and related social and economic concerns. As demand management practices affect low-income households most strongly, social equity issues need to be a major consideration in applying this form of initiative to achieve a more sustainable transportation system.

Taxes on transportation-related items such as parking and vehicle ownership have been used to some extent. The B.C. government is considering implementing a tax on parking throughout the Greater Vancouver Regional District, primarily to raise operating funds for transit, but also to curb automobile use and stimulate transit ridership. In 1992, the Ontario government implemented an additional sales tax on the purchase of new passenger vehicles. This gas guzzler tax ranges from $75 to $7 000 in seven categories, depending on the extent to which a vehicle exceeds a fuel

Table 11.30

Sustainable urban travel: initiatives and interactions

Measures of more sustainable urban travel / Major types of initiatives	REDUCED VEHICULAR TRAVEL EFFORT				GREATER CONSERVATION		IMPROVED ENVIRONMENTAL QUALITY		IMPROVED ECONOMIC EFFICIENCY OF RESOURCES		ENHANCED QUALITY OF LIFE		BROADENED LIFESTYLE CHOICES	
	Shorter trips	More walking	More transit	More cycling	Fossil fuels	Farm-land	Air emissions	Water runoff	Less congestion	Lower transportation costs	Greater safety	People places	Housing types	Travel modes
Transportation infrastructure	○	○	●	◉	●	◉	◉	◉	●	●	●	●	◉	●
• high-speed rail			◉		◉	○	◉		○		○			◉
• gap-filling and maintenance									[illegible]		[illegible]			
• environmental assessment as a planning tool	○	○	○		[illegible]	[illegible]	[illegible]	[illegible]						
• ecosystem approach to planning	○	○	○	○	◉	◉	◉	◉			○	◉	○	○
• continuous, multimodal arterial roads[a]	◉	◉	●	◉	○		◉		●	○	○	◉		◉
• high-occupancy vehicle facilities[a]	○	◉	●	◉	●	◉	●	●	●	●	●	●	○	●
• rapid transit and commuter rail networks[a]	○	◉	●		●	●	●	●	●	○	●	●	◉	●
• local transit improvements[a]		◉	●	○	◉	○	◉	◉	○	○	○	●	○	●
• cycle and pedestrian ways[a]	●	●	◉	●	●	◉	●	●	●	◉	●	●	○	◉
Demand management	◉	○	◉	○	◉	○	◉	○	●	◉	○	○	○	○
• parking price management[a]	●	◉	○	◉	●		●	●	●	●	◉	◉	◉	
• road pricing	○	◉	●	◉	◉	◉	◉	◉	●	◉	○	◉		○
• alternative work schedules[a]	○				○		○		○					
• ridesharing[a]	○				○		○		○	○				
• telecommuting[a]	◉				○		○		○					
• carbon/fuel/vehicle taxes	●	●	●	●	●	●	●	●	●	●	●	●	○	◉
• emission trading/permit programs			◉	○	◉		◉	◉	●	◉	◉	○		◉
• general application of full-cost accounting and user-pay principles		○			◉		◉	○	●	●	◉	○		◉
Traffic management	○	○	○		○		◉	◉	○	○	◉	○		
• advanced traffic management systems (intercity)	◉	○	●		○		◉	◉	◉	◉	◉			
• driver information systems (intercity)	○	○	◉	○	◉		◉	○	◉	○	◉			
• transportation of dangerous goods (regulations/practices)						○	●	●		○	●			
• automatic vehicle identification/location in freight movements							○		○	●				
• traffic calming[a]		○	●	○	○						●	●		
Cleaner vehicle technology					●		●	◉						
• low-emission and alternative fuel vehicles					●		◉	◉						
• energy-efficient vehicles					●		●				○			
• emission monitoring/testing programs					◉		●	●			○			
• standards/regulations for achieving the above					○		○	○	○	○	○			
Education and outreach	○	○	○	○	○		○		○	○	○	○		
• awareness – environmental consequences of transportation	○	○	○	○	○		○				○	○		
• encouraging alternative modes		○	○	○	○		○		○	○	○			
• encouraging efficient travel/driving habits	○				○		○			○				
Transit management[a]	◉	●	●	●	●		◉	◉	◉	●	◉	●	◉	●
• fare integration and schedule coordination[a]		○	●		◉	◉	●	●	●	●	●	●		●
• transit priority[a]		○	◉		◉	◉	◉	◉	◉	◉	◉	◉		◉
• traveller information systems[a]	○	○	◉	○	◉		◉	○	◉	◉	○			
Urban structure and design[a]	◉	●	●	●	●	●	◉	◉	◉	●	◉	●	◉	●
• compact mixed land use[a]	●	●	●	●	●	●	◉	◉	◉	●	●	●	●	●
• pedestrian-friendly streets[a]	○	●	●	●	●	◉	◉	◉	○	○	●	●		◉
• joint transportation/land use planning[a]	◉	●	●	●	●	●	●	●	●	●	◉	●	◉	●
• development nodes and intermodal transfer nodes[a]	○	◉	●	○	◉	◉	◉	◉	●	●	◉	●	●	●
• parking supply management[a]	○	◉	●	◉	◉	◉	◉	◉	●	◉	◉	◉		

LEGEND ● Large impact ◉ Moderate impact ○ Modest impact Negligible impact (blank in table)

[a] Initiatives exclusive to urban areas.

Source: IBI Group (1993).

consumption threshold of 6.0 L per 100 km. Sport utility vehicles are also taxed, but at a different rate.

Toll roads were once fairly common in Canada, particularly in Quebec. They virtually disappeared by the beginning of the 1980s, when transportation funding was not a major issue. Today, toll facilities are confined largely to bridges, but fiscal pressures have caused governments to examine the issue once again. In at least five provinces, formal road pricing studies have been completed or are under way. A major new highway in the Greater Toronto Area, Highway 407, is being constructed as a toll road featuring automatic toll collection. Although the impetus for tolling is to raise capital funds for accelerated construction, the potential for using congestion pricing (higher prices on toll roads during periods of peak use) as a demand management tool is also being addressed.

More thorough and far-reaching recommendations on transportation demand management have recently (1995) been provided by the Transportation and Climate Change Collaborative (1995) to the Province of Ontario. The report's recommendations on full-cost transportation pricing were aimed at making transportation systems more sustainable by decreasing market distortions caused by subsidies and other external factors.

Traffic management practices

A number of Canadian areas have implemented innovative practices designed to make better use of existing roads.

The Greater Toronto Area currently features four highway traffic management systems operated by the Province of Ontario. The systems consist of traffic sensors and video cameras that feed traffic data to operators and computers in control centres. The control centre identifies accidents and related events, dispatches response personnel to clear the problems, and uses driver information systems such as variable message signs and media interfaces to alert drivers to difficulties and ways of avoiding them. In Vancouver, a similar system operates in a critical tunnel link, whereas Montreal is currently planning such a system for its major urban expressways.

Cleaner vehicle technology

Canada is blessed with significant reserves of natural gas, and it is not surprising that the use of ATFs has been a feature of Canadian transportation. As with demand management practices, interest and research and development effort in the ATF field waxed and waned with the energy crises of the 1970s and 1980s. The early 1980s saw an aggressive push by provincial and federal governments in the field, resulting in record conversions of government, utility, and commercial fleets to propane and natural gas. Since then, vehicle attrition and declining conversion rates have reduced the Canadian ATF fleet to the point where electric, natural gas, propane, and alcohol vehicles accounted for less than 2% of the on-road transportation fuel consumed in Canada in 1991 (Natural Resources Canada 1993).

However, there has been a resurgence in ATF interest as a result of potential environmental benefits. In the field of urban transportation, there are about 110 natural gas buses in regular operation across Canada, particularly in the Hamilton and Toronto areas. After extensive field testing, methanol buses are now part of the operational fleet in Windsor. Vancouver is testing two hydrogen fuel cell buses, the first of their kind in the world, as the result of a cooperative effort of the federal government, the Province of British Columbia, and a private firm (Ballard Power Systems). Research and development of ATFs have received a continuing commitment from the federal government as part of its National Action Program on Climate Change, with current effort focusing on electronic controls, lightweight natural gas cylinders, infrastructure, and other issues (Government of Canada 1995a).

Industry associations representing ATF suppliers also have in place marketing and research and development programs aimed at increasing the market share of ATF vehicles, largely by promoting their environmental benefits. For example, the recently formed Natural Gas Vehicle Industry Alliance plans to increase natural gas vehicles in Canada from the current 38 000 to 300 000 by 2005. Private sector research firms, partially funded by provincial and federal government grants, have developed technological innovations such as the world's first electronic fuel injection system for gaseous fuels and a home refuelling unit for natural gas vehicles.

Emission standards and other regulations have long been used to improve the emission performance of individual vehicles. However, because of Canada's small share of the global vehicle market, our direct role in setting regulations has been limited. Emissions from air and marine sources are governed by international agreements. Through the *Motor Vehicle Safety Act*, Canada has been successful in establishing voluntary vehicle emission reduction programs that are identical to the regulated emission requirements in the United States and among the most stringent in the world.

The endorsement of the recommendations stemming from the Task Force on Cleaner Vehicles and Fuels by the Canadian Council of Ministers of the Environment (CCME 1995a) in October 1995 will result in new standards for cleaner gasoline and diesel fuel in Canada and also initiate a new program for low-emission vehicles no later than 2001. Under this program, all vehicles sold in Canada by 2001 will be required to include new technology to reduce tailpipe emissions by up to 70% from current levels (Thompson Gow and Associates 1995).

There is also work under way to improve the environmental performance of in-use vehicles. The City of Calgary instituted Smog Free, Canada's first large-scale voluntary emission testing program for all types of road vehicles, whereas a coalition of authorities in the Vancouver Region has implemented AirCare, Canada's first, and North America's most comprehensive, mandatory inspection and maintenance program for in-use vehicles. Through this program, 1 million light-duty vehicles have been inspected, resulting in 113 000 fewer tonnes of greenhouse gas emissions and 25 million fewer litres of gasoline consumed in

British Columbia's Lower Mainland. The NOx/VOC Management Plan of the federal government includes a number of transportation initiatives, such as NOx/VOCs motor vehicle emission standards, improved urban transportation management, reduced heavy-duty vehicle speeds in the summer, and a proposed national motor vehicle inspection and maintenance program.

Over the longer term, the federal government is committed to zero-emissions vehicle research (including electric and hydrogen fuel cell vehicles). The program will focus on the development of vehicle components such as advanced energy storage systems.

Education and outreach

A number of governmental and non-governmental organizations have recently been undertaking public awareness programs to stress both fuel efficiency when driving and the environmental benefits of alternatives to car use, such as buses, bicycles, and walking. For example, the Canadian Urban Transit Association's Modal Shift project includes a substantial outreach program to reverse the trend towards declining transit ridership, as does Montreal's "transit revival" program. Winnipeg Transit recently undertook a "green bus campaign," in which 10 buses were painted green and white as part of a major multimedia publicity effort to stress the environmental benefits of public transit. In centres such as Ottawa, Calgary, and Victoria, cycle commuting systems are being developed and promoted. Other programs by Environment Canada and Health Canada, including Action 21, Active Living, and Envirodollars, also encourage Canadians to use their car less frequently and to try alternative modes (Government of Canada 1995a).

In addition, a number of joint public–private sector initiatives have been developed to encourage the Canadian driving public to consider fuel efficiency when driving, maintaining, and purchasing vehicles. For example, Natural Resources Canada's AutoSmart Program provides information, training in fuel efficiency for new drivers, and a variety of initiatives with the private sector to promote fuel efficiency in road transportation.

Transit management and urban structure and design

Initiatives to make transit systems more efficient and attractive and to create more compact, mixed-use, and pedestrian-friendly land use patterns can significantly affect transportation sustainability. These topics are more fully addressed in Chapter 12.

Relative importance of the various initiatives

Best-guess estimates of the relative importance of the various sustainable transportation initiatives are given in Table 11.30. Of the seven major categories, three stand out as particularly important, because they have a large anticipated impact on a majority of sustainability measures. These categories, which are of particular relevance in urban centres, are:

- demand management;
- transportation infrastructure; and
- urban structure and design.

As for the other four categories, the following can be concluded:

- *Traffic management and education/ outreach* are essential requirements for making the most efficient use of existing road infrastructure. Education/outreach programs are vital in motivating lifestyle changes, particularly among young people at the elementary and high school level. The extent to which traffic management practices and outreach programs are implemented can have a significant effect on the success and cost-effectiveness of both demand management practices and transportation infrastructure improvements.
- *Transit management practices* are not rated as having a large impact on any one of the sustainability yardsticks; nevertheless, they represent an important set of initiatives, as they have a moderate impact on five of the six sustainability yardsticks.
- *Cleaner vehicle technology* development is a more specialized initiative, with important impacts on achieving greater conservation of resources and improved environmental quality, but with moderate or modest effects on the other sustainability yardsticks.

It is also useful to provide a broad summary of the status of current Canadian initiatives, as in Figure 11.51, where the implementation status of the various initiatives is shown in terms of four stages — talking, planning, acting, and accomplishing.

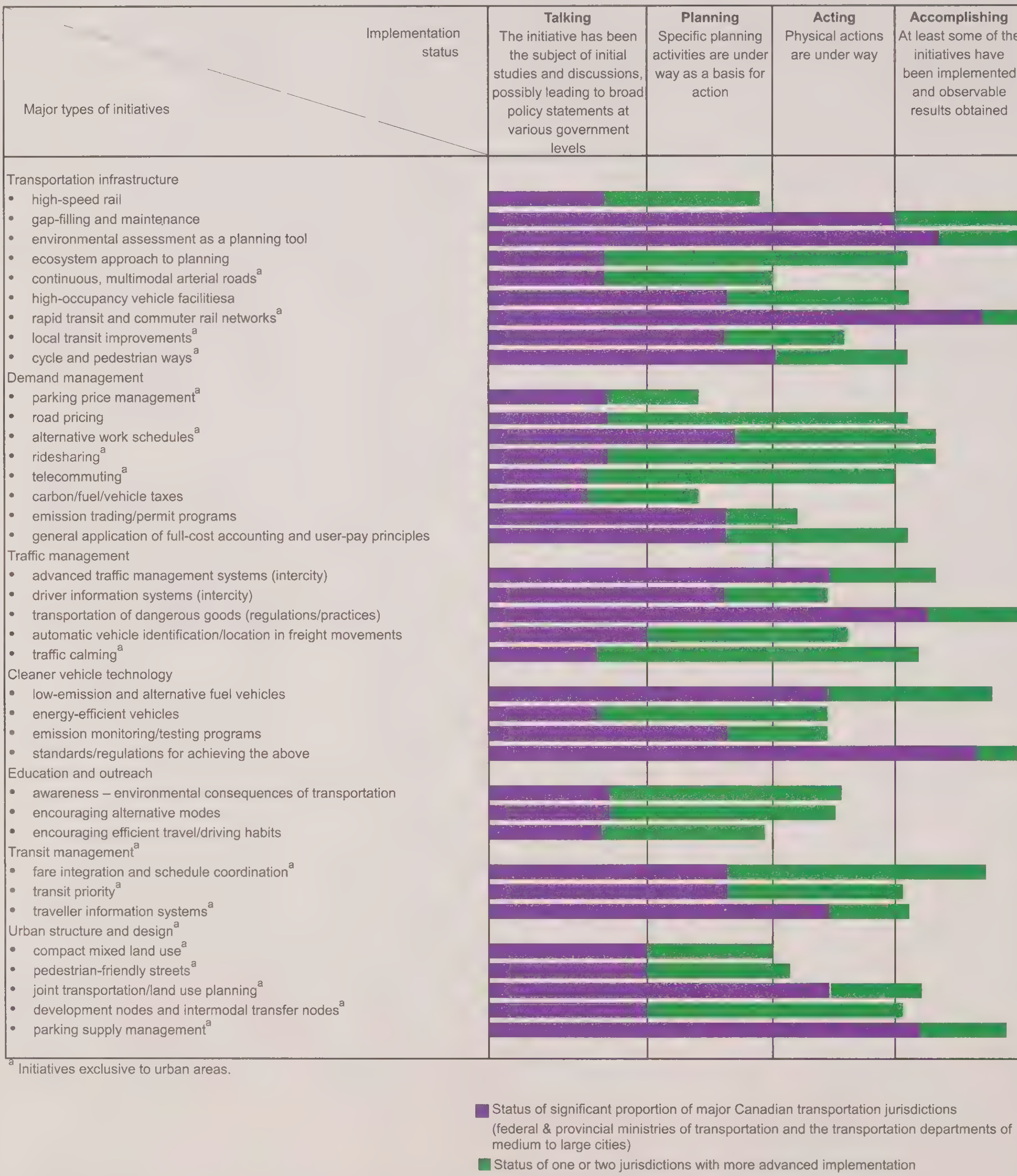
This very broad status report indicates that Canadian regions are at various stages in implementing the major types of initiatives towards more sustainable transportation. A significant number of Canadian jurisdictions are at either the talking or planning stage for the majority of the sustainable transportation initiatives, whereas one or two jurisdictions are at the acting or accomplishing stage on a particular initiative, leading the way towards more sustainable transportation in Canada.

Conclusion

This section has explored the basic dilemma inherent in Canada's transportation systems and practices today — on the one hand, transportation is absolutely essential to Canada's economic and social fabric; on the other hand, current transportation practices in Canada seem unsustainable from an environmental perspective.

In the past two decades, Canada has taken a number of steps towards sustainable transportation, particularly with technological and regulatory approaches to increase fuel efficiency and reduce vehicle emissions. However, it is apparent that — failing major breakthroughs — technological innovations to vehicles and infrastructure will not be sufficient if Canadians are to succeed in implementing a more sustainable transportation system. In addition to technological advances, fundamental behavioural changes that affect transportation demand will be required if Canada's transportation system is to move significantly towards sustainability.

Figure 11.51
Broad status of current Canadian initiatives towards more sustainable transportation



Source: IBI Group (1993).

Are individual Canadians willing to make such changes in behaviour? Some are, but a large number of others expect and, in many cases, require a high degree of mobility. Canadians are still strongly attached to the lifestyle and freedom the automobile provides. Are Canadians willing to take any actions that may reduce their mobility? These are likely to be limited as long as many trips are considered a necessity — for work, shopping, or child care, for example — rather than a choice. Given current land use patterns and financial circumstances, a practical choice of an alternative mode may be limited. Are governments willing and financially able to pursue long-term transportation initiatives? Although most of the initiatives described above will ultimately result in a more energy-efficient, cleaner, more attractive, and, therefore, more competitive economic environment, there may be some short-term negative impacts on economic competitiveness and community stability. In a time of increasing global competition, is Canada willing to be among the first nations to seriously tackle this problem?

Even given a high level of social and political will, modifying our demand for transportation will be neither easy nor quick. Our automobile-oriented land use patterns have built-in inertia — many housing and commercial developments will last for 50 years or more, and in any given year only a small fraction of an urban area is redeveloped. Thus, more intensive land use patterns that would be conducive to public transit, cycling, and walking will take years to emerge, even if the necessary steps are taken today. While investment, taxation, and pricing policies for sustainable transportation would favour the cleaner modes, our current subsidies for external costs that are not factored into direct transportation costs — for example, infrastructure, pollution, and accidents — are skewed towards the least sustainable modes. Also, transportation involves every member of society — whether rich or poor, urban or rural, or in a large city or a small town — and all levels of government. Hence, an unprecedented degree of cooperation is required to effect long-term, sustainable, and equitable solutions. Finally, our ability to track progress is hampered by lack of good data, particularly on passenger travel by automobile and goods movement by truck, although some new databases, such as the National Energy Use Database, are beginning to respond to this need.

These questions and constraints are daunting. However, there are signs that Canada is responding to these challenges in a positive way. The review of initiatives above indicates that a great many jurisdictions across Canada are undertaking local actions to improve the sustainability of transportation. In addition, Canada has initiated or been a party to many recent global environmental initiatives. These include the Framework Convention on Climate Change (which has spurred the development of both a National Action Program and a Federal Action Program on Climate Change), the Nitrogen Oxide Protocol, the Volatile Organic Compounds Protocol, and the Canada–United States Air Quality Agreement. Transportation is a critical component of plans to meet international obligations and move towards sustainability.

These actions are a step in the right direction but in themselves will not likely be sufficient to reverse long-standing trends of increasing, and increasingly unsustainable, transportation activity. At this point, it is unclear whether Canada has the will to take the next steps along the pathway to more sustainable transportation. What is clear is that Canadians possess many of the tools, skills, and resources to do so.

Manufacturing

Introduction

Manufacturing, like other economic activities, consumes energy and resources. It also produces emissions that, if improperly managed, can affect the quality of the air, water, and land. These, in turn, can degrade overall ecological integrity. Emissions of toxic substances and other pollutants into the environment and depletion of fossil fuels and other nonrenewable resources cannot be sustained indefinitely. Sustainable development in this sector demands a balance between the social and economic benefits provided by manufacturing and the maintenance of ecological integrity.

The following pages provide an overview of the relationship between manufacturing and the environment and examine the measures being taken to mitigate the negative effects of this relationship. Also discussed are the ways in which manufacturing industries can become more sustainable, primarily through the application of pollution prevention approaches such as "green design" and industrial ecology and the use of economic and regulatory instruments. The objective is to provide a perspective on the significance of the many secondary processing and manufacturing activities that take place in Canada to the current state of the national environment.

Table 11.31 lists the sectors covered in this component of the chapter. For the purposes of this review, manufacturing includes secondary processing and manufacturing (e.g., fabricated metals) and final products manufacturing (e.g., automobiles). It does not, however, include the following, which were dealt with elsewhere in this chapter: primary resource extraction and processing (e.g., mining and smelting, which were dealt with in the "Minerals, metals, and mining" component); primary processing, such as pulp and paper making (see "Forestry"); and petroleum refining (see "Energy use").

Manufacturing in Canada

Socioeconomic profile

Manufacturing is a significant component of Canada's economy. In 1993, some 39 000 manufacturing establishments generated 18% of the country's GDP at factor cost (i.e., the cost of the factors of production such as capital and labour), a value of approximately $100 billion (Statistics Canada 1994e; national database, State of the Environment Directorate, Environment Canada). Figure 11.52 reveals, however, that, since 1961, the

manufacturing sector's share of Canada's GDP has been declining steadily relative to that of the service sector, as activities such as banking, resale and wholesale trade, restaurants, construction, transportation, and communications have come to constitute a proportionately larger part of the Canadian economy. Nonetheless, for this period, the value of manufacturing production, expressed in constant dollars (i.e., reflecting real output over a period, without factoring in increases in dollar value due to inflation), almost tripled.

In 1993, total shipments from manufacturing establishments to both domestic and export markets were valued at approximately $300 billion (net selling value). The sector as a whole employed 1.8 million persons in 1993, representing 13% of the Canadian labour force (Statistics Canada 1994e; national database, State of the Environment Directorate, Environment Canada). The largest components of the manufacturing sector, in terms of share of GDP, include transport equipment, food processing, chemical products, electrical products, printing and publishing, and fabricated metals. Together, these six industries account for over 60% of the GDP of the manufacturing sector (Fig. 11.53). Table 11.32 presents a provincial breakdown of the number of manufacturing establishments, employment, and value of shipments.

Most of Canada's manufacturing activity is concentrated in two of the seven ecozone groupings: about 70% is located in the Great Lakes–St. Lawrence region, primarily in the Windsor–Quebec City corridor (see Chapter 6), and about 20% is located in the Pacific and Western Mountains, primarily in British Columbia (see Chapter 3). A number of historical and geographical factors have shaped the current spatial distribution of Canadian manufacturing industries. These include:

- proximity to markets, both domestic and in the United States;
- access to rivers, canals, railways, highways, and other transportation systems; and
- access to production inputs (in the case of energy-intensive industries, this includes relatively inexpensive and abundant energy sources) and labour pools.

Despite advances in transportation, communications, and production techniques, these factors continue to be of prime importance to the manufacturing sector.

Table 11.31
Manufacturing industries covered by the component

Standard Industrial Classification	Industry
10	Food (e.g., dairy, bakery, edible oil, and canned products)
11	Beverage (e.g., soft drink, beer, wine)
12	Tobacco products (e.g., cigarettes)
15	Rubber products (e.g., tires, tubes, hoses, belts)
16	Plastic products (e.g., foam, pipe, film, bags)
17	Leather/allied products (e.g., tanneries, footwear, luggage)
18	Primary textiles (e.g., human-made fibres, knitted fabric)
19	Textile products (e.g., carpets, canvas, natural fibre processing)
24	Clothing (e.g., coats, gloves)
25	Wood (e.g., shingles, lumber, plywood, doors, boxes, pallets, coffins)
26	Furniture (e.g., household furniture)
28	Printing and publishing (e.g., books, newspapers)
30	Fabricated metal products (e.g., boilers, wire, tools, cutlery)
31	Machinery (e.g., commercial refrigeration, agricultural implements)
32	Transportation equipment (e.g., planes, trains, automobiles)
33	Electrical/electronic products (e.g., appliances, computers, phones)
35	Nonmetallic mineral products (e.g., cement, concrete, glass, gypsum)
36	Refined petroleum/coal products (e.g., oil, grease)
37	Chemicals/chemical products (e.g., pesticides, resin, pharmaceuticals)
39	Other manufacturing (e.g., clocks, sporting goods, toys)

Source: Statistics Canada (1995b).

Socioeconomic and environmental linkages

The interaction of various manufacturing industries with the environment differs according to the type of raw materials and production processes used, the degree of finishing of the final product, consumer product demand, legislation, and other socioeconomic and environmental factors. Figure 11.54 illustrates this interaction in a simplified way by delineating the flow of energy, materials, wastes, capital, labour, and other factors within the industrial subsystem. This process is driven by consumer demand operating within a market economy. Of course, the nature of consumer demand itself is determined by such factors as advertising, consumer awareness, and the range of products available for consumption. For consumers to make environmentally responsible purchasing decisions, access to life cycle assessments of products is also necessary (see the section on "Life cycle assessment" below).

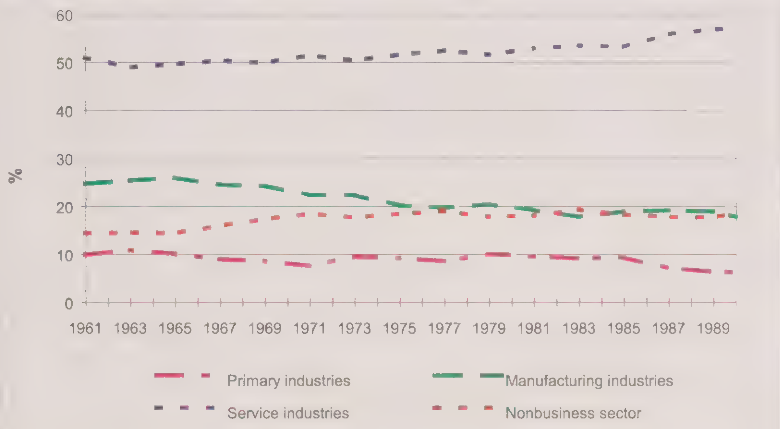
In such a system, the generation of postconsumer waste is inversely proportional to consumer demand for more "environmentally friendly" products (i.e., an increase in demand for commodities with less packaging or an avoidance of overpackaged or disposable commodities will lead to reduced waste generation). This simplification does not, however, account for factors such as the influence of tradeoffs among ecological sustainability and economic growth, technological change, regulations and incentives governing pollution, and sociocultural values influencing consumer behaviour. Thus, the market for recycled products is shaped not only by consumer demand but also by other con-

siderations, such as health regulations that prohibit the use of recycled material in packaging for food products.

International trade of manufactured goods

Exports are significant for the economic health of most nations that are well integrated into the global economy. Exports are a means of extending markets and thus increasing earnings. In Canada, the volume of exports, as a percentage of total production, varies according to the particular manufacturing industry. For example, in 1990, 74% of the automobiles and other transportation equipment produced was exported. This high percentage of exports was primarily due to the Auto Pact, which guarantees tariff-free movement of vehicles and parts across the United States–Canada border. In contrast, export propensities (defined as a particular commodity's tendency to be exported as a percentage of the total value for production) for tobacco products and for fruits, vegetables, and other related products were 6% and 9%, respectively (Statistics Canada 1994b). In general, Canadian products that are more intensive in terms of energy and other resources tend to have higher export propensities. Reasons for this pattern include Canada's comparative advantage with respect to energy and other resources. This comparative advantage is based on abundant supplies of hydroelectricity and minerals, a well-developed infrastructure for extracting, processing, and using energy and other resources, a skilled labour force, and other factors.

Figure 11.52
Distribution of gross domestic product at factor cost, by industry, 1961–1990



Source: Statistics Canada (1994b).

Figure 11.53
Share of gross domestic product, by industry, 1991

Source: Statistics Canada (1994b).

Establishing a direct link between international trade and environmental effects is difficult, however, because of the problem of distinguishing quantitatively between the environmental effects of manufacturing for domestic consumption and those relating to foreign consumption. This becomes more difficult as the products become more refined. Moving from a semifabricated stage to a final product implies the incorporation of a diverse range of additional materials and production processes, all of which possess implications for the environment.

One way of making a link, however tentative, between the export of manufactured products and the environment is to look at their energy intensities (Statistics Canada 1994b). Table 11.33 illustrates a general decrease in the energy requirement per dollar of production between 1981 and 1990 — primarily as a result of the more efficient use of energy. Nevertheless, total energy requirements for most exported products increased during the same period as the volume of exports increased. The export of Canadian energy, as embodied in manufactured products, means that Canada bears the environmental effects of energy extraction and use. In other words, countries that import Canadian commodities avoid most of the environmental costs associated with their production. However, Canada avoids most of the environmental costs associated with the manufacture of products that it imports.

Environmental issues related to manufacturing

This section focuses on selected aspects of the relationship between manufacturing and the environment. It examines the use of energy and other resources, atmospheric issues, water use and quality, and the generation of solid and hazardous wastes. It also outlines measures taken by manufacturing industries to function more sustainably.

The use of energy and other resources

The environmental effects associated with the use of energy and other resources are attributable to all sectors of the economy. Although not as resource intensive as some other sectors, manufacturing nonetheless contains industries that use significant amounts of energy, fossil fuel products, forestry and agricultural products, and other resources. The figures in Table 11.34 are energy and resource intensity measures calculated as the percentage of the value of energy and resource inputs to total outputs for each industry. In other words, in proportion to their output, certain manufacturing activities use more energy and resources than other activities. Generally speaking, the greater these intensities, the greater the effect on the environment, although factors such as technology can help to mitigate environmental effects.

Table 11.34 reveals, for example, that the manufacture of chemical products is more energy intensive than the manufacture of fabricated metal products. This is due to the need to break chemical bonds and to purify solutions. The calculation of resource intensity is related to the perceived environmental implications associated with the harvesting and processing of particular resources. Thus, commodities that primarily use water, beverages for example, are considered to be less resource intensive than commodities, such as building materials, that are mostly composed of wood.

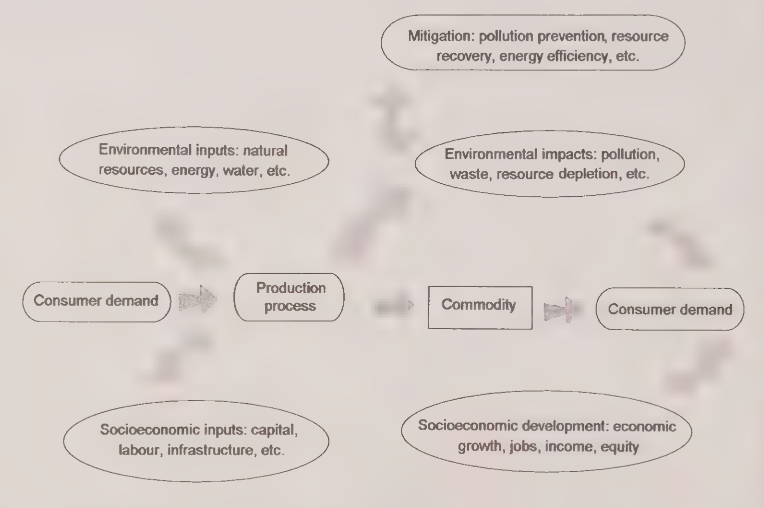
The relative environmental impact of a manufacturing activity, as indicated by its resource use intensity, is related to both the inputs and outputs of the processes it uses. For example, resource-intensive processes consume both renewable and nonrenewable resources, including wood, water, minerals, and fossil fuels. The sustainable development issues associated with these uses include the depletion of nonrenewable resources and effects related to the extraction of fossil fuels, such as land disturbance. Furthermore, the transformation of large quantities of raw materials into finished or semifinished products may produce large amounts of by-products — which are increasingly being recycled or reused in the production process — and wastes that must be disposed of appropriately.

Table 11.32
Selected manufacturing statistics, by province/territory, 1990

Province/territory	No. of establishments	Total no. of employees	Value of shipments ($, 000s)
Newfoundland	333	15 610	1 551 715
Prince Edward Island	141	3 486	396 431
Nova Scotia	742	34 012	4 521 000
New Brunswick	687	27 425	4 351 273
Quebec	13 004	450 279	64 114 458
Ontario	15 001	827 312	138 569 400
Manitoba	1 125	49 104	5 874 234
Saskatchewan	809	20 234	3 785 954
Alberta	2 765	85 236	18 379 472
British Columbia	4 011	129 154	19 514 143
Yukon/Northwest Territories	54	443	75 421
Total	38 672	1 642 295	261 133 501

Source: Statistics Canada (1994i).

Figure 11.54
Major links and flows of an industrial system in a socioeconomic context



Source: Adapted from Tolba et al. (1992).

In the case of fossil fuels, the intensity of use can have an environmental significance beyond the depletion of nonrenewable resources. The combustion of fossil fuels results in the emission of certain pollutants that affect air quality and contribute to acidic deposition and climate change. An energy source such as hydroelectricity engenders environmental effects through the damming of water bodies. And, in the instance of nuclear power, there exist certain intractable problems related to the disposal of radioactive waste.

Many of the environmental effects of manufacturing can be mitigated through responses such as the redesign of manufacturing processes, material substitution, and the use of more efficient or alternative energy sources (like cogeneration, for example, which uses waste heat or steam from a manufacturing process to produce electricity). As well, the reuse and recycling of products and their components constitute a significant opportunity to conserve both energy and resources. A case in point is the manufacture of a beverage container from recycled aluminum, which utilizes a mere 5% of the energy required to manufacture a can from primary aluminum.

Atmospheric change

Historically, the smokestacks of manufacturing industries have been associated with progress and economic growth. Indeed, belching smokestacks were once a symbol of industrial development and of a nation's place in the modern world economy. The cumulative effects of a multitude of smokestacks and their emissions, however, have prompted a reassessment of the environmental costs of development. With the emergence of prominent issues such as acidic deposition and climate change, the public has become more aware of the economic and social consequences of pollution and the limits of the atmosphere's capacity to absorb anthropogenic pollutants.

Table 11.33
Energy requirements of exports, 1981 and 1990

Commodity	Export propensity (% of production)	Energy requirements (10^6 J) per 1986$ of production		Export energy requirements (10^{12} J)	
	1990	1981	1990	1981	1990
Food processing	8.8	33.9	32.0	69.1	75.8
Beverages	11.2	13.1	12.3	11.7	8.8
Tobacco products	5.7	10.8	10.8	1.9	0.9
Rubber, leather, plastic products	25.8	20.9	18.2	17.0	33.9
Textile products	15.5	21.4	19.1	10.9	16.4
Clothing	5.3	11.7	11.4	3.4	3.8
Wood products	39.4	15.6	13.4	75.7	81.3
Furniture and fixtures	15.6	13.4	13.0	5.2	9.0
Printing and publishing	3.6	12.0	13.2	3.4	5.5
Metal fabricated products	13.0	23.3	20.5	36.5	38.3
Machinery and equipment	51.2	14.9	11.9	78.2	80.2
Transportation equipment	73.7	16.5	13.6	335.0	532.9
Electrical/communication products	35.3	11.5	9.8	28.6	48.1
Nonmetallic mineral products	12.4	36.6	34.7	25.5	27.6
Chemical products	24.4	33.1	29.5	127.7	186.1
Other manufacturing	37.5	15.2	14.6	22.3	37.5

Note: Export energy requirements = energy requirements per $ of production x $ value of exports.
The joule (J) is the internationally accepted standard unit for measuring all forms of energy. A litre of gasoline typically contains 35 MJ (35 x 10^6 J) of energy.

Source: Adapted from Statistics Canada (1994b).

The following section assesses the contribution of manufacturing to the issues of air pollution, greenhouse gas emissions, and ozone depletion and identifies steps towards mitigation.

Air pollution

Although not the only source, the manufacturing sector is commonly linked to the following common categories of air pollutants: sulphur dioxide, nitrogen oxides, hydrocarbons, VOCs, and particulates (see also Chapter 15 and the "Atmosphere" section of Chapter 10). Figure 11.55 illustrates the emissions of the manufacturing sector relative to such activities as transportation and stationary fuel combustion.

Sulphur dioxide combines with oxygen and water in the atmosphere to form sulphuric acid, the major component of acidic deposition, or acid rain. Manufacturing released 23% of total sulphur dioxide emissions in 1990, with cement and concrete manufacture and petrochemical production the major sources (Environment Canada 1993c).

Nitrogen oxides is the collective term for a variety of gases that are combinations of nitrogen and oxygen. Nitrogen dioxide (NO_2), in particular, contributes to the formation of smog. Manufacturing accounted for 4% of total nitrogen oxide emissions in 1990, with chemical and cement production the leading contributors (Environment Canada 1993c).

Hydrocarbons are organic compounds containing only hydrogen and carbon and include a diverse number of air pollutants with differing toxicological and environmental properties. Among the most troublesome pollutants in this category are methane, which is a greenhouse gas, and PAHs, some of which are carcinogenic.

VOCs, of which over a hundred different varieties are emitted in Canada, are linked to the formation of ground-level ozone. Printing on plastics and other manufacturing activities accounted for 4% of total emissions in 1990 (Environment Canada 1993c).

The particulates category includes dust, soot, asbestos, lead, and other types of

solid particles, as well as oil, sulphuric acid, and other liquid particles. Particulates are emitted by many manufacturing processes, which together accounted for 21% of total emissions in 1990 (Environment Canada 1993c).

Greenhouse gas emissions

Carbon dioxide, methane, nitrous oxide, and certain other atmospheric gases have strong capabilities to absorb and reradiate infrared energy, thus contributing to what is termed the "greenhouse effect." Although occurring naturally in the atmosphere and produced by various natural phenomena, concentrations of these greenhouse gases have been increasing as a result of the combustion of fossil fuels, agricultural practices, and various other human activities (see Chapter 15 and the "Atmosphere" section of Chapter 10). The enhancement of the naturally occurring greenhouse effect as a result of increased emissions of these gases has been an issue of concern nationally and internationally for several years now. Canada has signed the United Nations Framework Convention on Climate Change, with the aim of returning net emissions of carbon dioxide and other greenhouse gases not controlled under the Montreal Protocol to 1990 levels by the year 2000 (Environment Canada 1995e).

Figure 11.56 illustrates that the carbon dioxide emissions of certain manufacturing activities represent about one-quarter of total carbon dioxide emissions. This figure reflects the direct and indirect emissions associated with a sector or commodity. Direct emissions originate from the production process itself, whereas indirect emissions are associated with the inputs to the production process, such as energy.

In terms of combined emissions of carbon dioxide equivalent — that is, emissions of carbon dioxide, nitrous oxide, and methane expressed as the amount of carbon dioxide that would have an equivalent warming effect — the most significant contributions from manufacturing come from nonmetallic mineral production (cement and lime production in particular) and chemical manufacturing.

Table 11.34
Intensity of the consumption of energy and other resources for selected industries, 1990

Industry	Intensities (%)	
	Energy	Resources
Food processing	1.1	30.5
Beverage	1.0	0.8
Tobacco products	0.4	13.8
Rubber products	1.9	0.6
Plastic products	2.0	0.2
Leather/allied products	0.8	0.2
Textiles	2.1	0.6
Clothing	0.6	1.0
Wood products	2.1	30.0
Furniture	1.1	0.2
Printing and publishing	0.7	0.1
Fabricated metals	1.3	2.8
Machinery	0.9	0.2
Transport equipment	0.7	0.1
Electrical products	0.8	0.1
Nonmetallic mineral products	5.0	10.3
Chemical products	5.8	2.4
Other manufacturing	1.0	3.3

Note: The energy and resource intensity values are calculated as the percentage of the value of energy and resource inputs to total outputs for each industry.

Source: Statistics Canada (1994b).

In terms of the greenhouse gas intensity of commodities (a ratio of greenhouse gas emissions to the delivery of $1 000 of a given commodity or service to a final consumer), cement and concrete products rank third in terms of carbon dioxide equivalent against other sectors of the economy (Smith 1993). Globally, cement production releases approximately 3% of carbon dioxide emissions (World Resources Institute 1994). The emissions of carbon dioxide during cement production occur during the reduction of calcium carbonate, which results in carbon dioxide and calcium oxide (Jaques 1992).

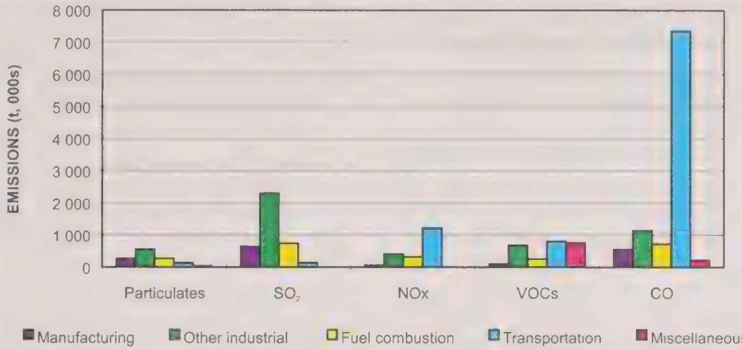
The greenhouse gas contributions of the chemical sector are primarily a result of carbon dioxide and nitrous oxide emissions. In terms of greenhouse gas intensity, industrial chemicals rank 14th, pharmaceuticals 15th, fertilizers 16th, and other chemical products 17th. Sources of greenhouse gas emissions include the use of fossil fuels for energy and chemical processing. The chemical industry is responding by reducing carbon dioxide emissions, when feasible, through increased energy efficiency. The industry also projects a significant reduction of nitrous oxide, CFCs, and methane. These measures are expected to reduce the global warming potential of emissions from the sector by about 45% between 1992 and 1998 (Canadian Chemical Producers' Association 1994).

Ozone-depleting substances

Ozone in the stratosphere, an outer layer of the Earth's atmosphere, partly filters out potentially harmful ultraviolet radiation from the sun. Depletion of ozone in this layer constitutes a potentially significant risk to organisms at the Earth's surface (see Chapter 15). CFCs are the major ozone-depleting substances. Other substances, with differing potential for ozone depletion, include carbon tetrachloride, methyl chloroform, methyl bromide, halons, and hydrochlorofluorocarbons (HCFCs).

Until recently, CFCs were widely used in manufacturing as blowing agents, solvents, and degreasers and in refrigeration sys-

Figure 11.55
Emissions of air pollutants, by sector, 1990



Note: "Other industrial" includes minerals and metals, pulp and paper, and energy. "Miscellaneous" includes incineration, dry cleaning, solvent use, etc.

Source: Residual Discharge Information System, Environmental Protection Service, Environment Canada.

tems used in processes within the chemical, petrochemical, and pharmaceutical industries. In 1993, the Canadian economy as a whole used 7 500 t of CFCs. The principal uses were mobile air conditioning (36%), foam blowing (29%), refrigeration and air conditioning (24%), and solvents (5%) (Commercial Chemicals Evaluation Branch, Environmental Protection Service, Environment Canada). CFC production in Canada, which used carbon tetrachloride as a raw material, ceased in February 1993. The use of CFCs in foam manufacturing processes was eliminated between 1993 and 1995.

The recognition of the risk posed by the depletion of the ozone layer has led to a significant global convention — the Montreal Protocol — which requires nations to cut their consumption and production of ozone-depleting substances. In November 1992, an accelerated phaseout schedule called for the elimination of new supplies of halons in January 1994 and elimination of new supplies of most of the other substances by January 1996. The use of HCFCs, which have a significantly lower ozone-depleting potential and are used as transitional substitutes for CFCs, is to be completely eliminated by 2020 (B. Angle, Atmospheric Environment Service, Environment Canada, personal communication). Canada's commitment to the Montreal Protocol has resulted in a significant decrease in the domestic supply of ozone-depleting substances, from a high of 27.8 kt in 1987 to 5.7 kt in 1994. This has occurred despite an increase in economic activity (Environment Canada 1995f).

Initiatives undertaken within the manufacturing sector to reduce emissions of ozone-depleting substances have centred on process and chemical substitution. For example, in the manufacture of printed circuit boards, Northern Telecom eliminated the need for CFC solvents by modifying its production process, essentially eliminating any need for solvents. The \$1 million investment resulted in savings of \$4 million between 1988 and 1991. Dow Chemical performed a similar production process change when it replaced CFCs used in the manufacture of insulation foam (Environment Canada 1994d). Some other production technology shifts, such as the replacement of chlorinated solvents with nonchlorinated or water-based substitutes, have also led to the complete elimination of ozone-depleting substances.

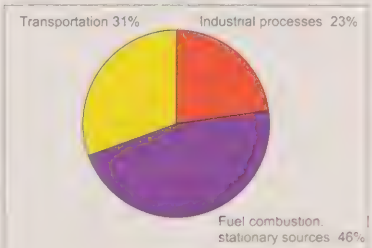
Emission control

Numerous technologies exist for the control of emissions into the air. Two general types of technologies are used: those designed for trapping particulates or pollutants and those designed to trap certain gases. Particulates are usually collected through such means as filters or electrostatic precipitators. Gaseous pollutants are controlled through absorption, incineration, wet scrubbers, and other methods that pass gases through a spray of water or other liquid, thus destroying or collecting the pollutant.

In many cases, to avoid clogging mechanisms, emissions pass through particulate control systems prior to treatment by gaseous control systems. One product of these technologies is solid waste or sludge, which may be hazardous and must be disposed of appropriately. Again, the use of particular technologies depends on the raw materials and the manufacturing processes used in the production of a commodity.

However, such technologies — often referred to as "end-of-pipe" solutions — are not the only means of controlling the emission of pollutants into the atmosphere. In the case of CFCs, recycling initiatives such as Canada's National Action Plan for Recovery and Recycling of CFCs also play an important role. In addition, the federal and provincial governments, in cooperation with the Heating, Refrigeration, and Air Conditioning Institute and municipalities, have developed a training program for the proper handling, recycling, and recovery of CFC refrigerants. Over 60 000 technicians have been trained (Government of Canada 1996).

Figure 11.56
Carbon dioxide emissions, by sector, 1993



Note: Total does not add up to 100% owing to rounding.

Source: Jaques (1992), unpublished data, Environmental Protection Service, Environment Canada.

Ultimately, though, changes to raw materials, manufacturing technologies, and operating procedures (following significant investments of time and money) may represent more economical and efficient approaches to emission control.

Water use and discharge

Whether it is incorporated into a product or used for cooling and cleaning, water is essential to most manufacturing processes. This dependence on water, which historically included waterborne transportation, has resulted in significant concentrations of industries such as food processing, chemical manufacturing, and metal finishing around the Great Lakes, the St. Lawrence River, the lower Fraser River, and other water bodies in other parts of the country. Most human activities, including manufacturing, have also used the aquatic environment. This has led to increased concern about water quality (see, for example, Chapters 3 and 6) and its effects on the health of humans and other living organisms.

The use of water

Manufacturing industries use water in three major ways (apart from its use in air emission controls):

- *As a component to be integrated into the product*: Food processing and chemical production, for example, are among the largest sectoral users of water.
- *As a means of cooling, condensing, and producing steam:* Chemical production is the largest user of water for this purpose.
- *For flushing pipes and equipment and other sanitary functions*: Food production is the largest user of water in this fashion (Tate and Scharf 1992).

Figure 11.57 illustrates the flow of water in an industrial system. Intake refers to water withdrawal from ground or surface sources and, combined with water recirculated during the manufacturing process, constitutes the gross use. Consumption refers to water used up (e.g., used as a reactant) or incorporated into the product. Discharge is water returned to the environment, whether treated or untreated (Tate and Scharf 1992).

In general, the quantity of water used depends on the manufacturing process. In 1991, the four largest sectoral users of water, for all purposes, were chemicals, foods, primary textiles, and plastic products. Table 11.35 shows trends in water use patterns for these selected industries. In most cases, water use and discharge declined between 1986 and 1991, except for the primary textiles and plastic products industries, which experienced an increase in production capacity during that period (Tate and Scharf 1992; unpublished data supplied by D. Scharf, Environmental Conservation Service, Environment Canada).

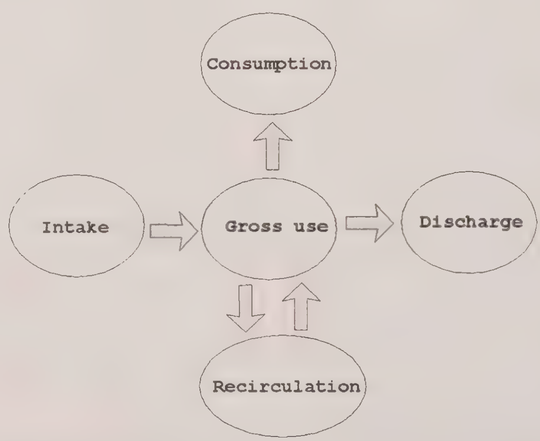
Discharge water

Water discharged from industrial processes may contain a variety of contaminants in varying degrees of concentration. Two broad categories of contaminants may be identified, based on their effects on the aquatic environment (OECD 1991; see also the "Fresh water" component in Chapter 10).

The first category consists of contaminants that affect the water's oxygen regime, which is essential for the survival of fish and other aquatic life. Biochemical oxygen demand (BOD) is a measure of oxygen consumed by the decay of certain contaminants, and the term BOD is often used as a convenient shorthand label for oxygen-depleting substances. Significant contributors to BOD include food manufacturing and organic chemical production. The discharges of these sectors pale, however, when compared with those of pulp and paper production. In 1991, in Ontario, pulp and paper discharges of BOD were almost 10 times (about 90 000 t) as much as the combined discharges from food processing and chemical manufacturing (Ontario Ministry of Environment and Energy 1993; Statistics Canada 1994b).

The second category consists of lead, mercury, cyanide, chlorinated solvents, and other toxic substances, all of which pose differing environmental and health hazards. Some of the processes that are significant in this respect are textile and chemical manufacturing and the production of microelectronics. Metal finishing (i.e., anodizing, chromium plating, galvanizing, and related processes) is also a significant contributor of toxic substances to the aquatic environment (OECD 1991).

Figure 11.57
The flow of water in an industrial system



Source: Tate and Scharf (1992).

For the most part, manufacturing facilities have attempted to minimize the effects of discharge water on the environment through wastewater treatment. In 1991, 41% of total discharge water was treated, up from 35% in 1986 (Tate and Scharf 1992; unpublished data supplied by D. Scharf, Environmental Conservation Service, Environment Canada).

The type of treatment received by wastewater is dictated by factors such as the size of a facility, the amount of wastewater generated, the type of pollutants contained in the wastewater, access to municipal treatment plants, and regulations covering discharge and water quality. Treatment options fall into three categories: primary, secondary, and tertiary. The following data on the use of these processes are based on Environment Canada surveys, conducted in 1986 and 1991, of selected establishments representative of different manufacturing sectors (Tate and Scharf 1992; unpublished data supplied by D. Scharf, Environmental Conservation Service, Environment Canada). The percentages cited here refer only to manufacturing sectors listed in Table 11.31.

Primary wastewater treatment, the simplest and least expensive treatment method, involves the use of screens, filters, coagulation, and other mechanical means to remove pollutants. Suspended solids also settle out as sludge. Approximately 76% of treated wastewater received primary treatment in 1991. Altogether, some 30% of total wastewater discharges received primary treatment in 1991, the same as in 1986.

Secondary wastewater treatment involves the use of biological treatment to remove degradable oxygen-demanding organic waste. Techniques include activated sludge and trickling filter methods. In 1991, 20% of treated wastewater (8.5% of total discharges) received secondary treatment. The volume of water receiving secondary treatment increased by 100% between 1986 and 1991. Compared with other industries, the food and beverage industries used secondary treatment for a significantly larger proportion of their wastewater.

Tertiary wastewater treatment uses chemical means to remove phosphorus and other nutrients and contaminants. This level of treatment is usually oriented towards the removal of specific pollutants and, as a consequence, is more expensive than primary and secondary wastewater treatment. In 1991, 3% of treated wastewater received tertiary treatment, a 100% increase over 1986.

In Canada, there has been a general increase in the number of initiatives and regulations governing the discharge of polluting and toxic substances into the aquatic environment. In 1988, for example, the St. Lawrence Action Plan (now the St. Lawrence Vision 2000) targeted 50 of the largest industrial polluters for a 90% reduction in discharges of liquid toxic waste into the St. Lawrence and Saguenay rivers. Although this goal has to a large extent been achieved, the relevant pollutant loadings in the aquatic environment have decreased by only 10%. That is because the 50 plants actually contributed only about 10% of the overall loadings. A much larger proportion came either from the Great Lakes (40%) or from tributaries (30%), whereas a variety of other sources (mostly atmospheric) accounted for another 20% (Centre Saint-Laurent 1994). Discharges from unregulated smaller plants must also be considered as continuing sources of pollutants.

Table 11.35
Water use by selected industries, 1986 and 1991

Industry group	Gross use (m³/year, millions)		Discharge (m³/year, millions)	
	1986	1991	1986	1991
Chemicals	3 232	2 290	1 615	1 219
Foods	712	540	540	320
Primary textiles	125	429	93	227
Plastic products	96	308	27	39

Source: Tate and Scharf (1992); unpublished data supplied by D. Scharf, Environmental Conservation Service, Environment Canada.

Accompanying the measures required by regulation — which target particular polluters or pollution "hot spots" — are the initiatives undertaken by manufacturing sectors and individual plants. The traditional approach to mitigating manufacturing's effect on the aquatic environment has used end-of-pipe technologies to clean the effluent before it is discharged into the water. Increasingly, however, there has been a move towards reducing the contaminant loading to wastewater and the volume of wastewater. This trend resulted in a 10% reduction in wastewater volume between 1986 and 1991 (Tate and Scharf 1992; unpublished data supplied by D. Scharf, Environmental Conservation Service, Environment Canada). The principal motives for these changes have been increased water and sewage service prices and more stringent regulations governing discharge (Ross 1994).

The substitution of nontoxic substances for toxic materials, changes to production processes, and wastewater audits are some of the means used to determine and reduce contaminant loading and wastewater volume. In a meat processing operation, for example, the adoption of such techniques can result in a 40% reduction in wastewater volume and an 81% reduction in costs associated with the wastewater treatment (Ross 1994).

Solid and hazardous waste

The generation of by-products is an inherent consequence of the manufacturing process. When these by-products cannot be reused or recycled, they must be disposed of. This section reviews the three main categories of waste associated with manufacturing: solid waste, packaging, and hazardous waste.

Solid waste

Manufacturing wastes include unprocessed raw materials, undesirable by-products, spent auxiliary materials such as catalysts, maintenance waste material, and off-specification products generated during shut-down and start-up (Hyatt and Baird 1993). Table 11.36 provides an indication of the type and relative proportions of solid waste generated by particular industries in Ontario.

Manufacturers deal with solid waste and by-products in two different ways. One approach is to deal with the waste and by-products after they have been generated through disposal, recycling, or reuse. Disposal, however, may result in the loss of potentially valuable materials and may create additional costs in the form of haulage and dumping fees. Consequently, disposal is increasingly being replaced by more sustainable practices such as recycling, which may be practised within the facility, within a sector, or within the economy as a whole. With the emergence of waste exchanges, the recycling of unwanted materials has become simpler. Through these organizations, waste material from one firm can be directed to another, which may then use the same material as input to a production process (for further detail, see the section on "Industrial ecology" below).

The second approach attempts to reduce the amount of waste and by-products generated in the first place. An emphasis on the adoption of low- and nonwaste technologies — which include, for example, the modification of production processes to use less raw material — can lead to further waste minimization. This streamlining of the production process, otherwise known as "dematerialization," often results in a more efficient operation, leading to a reduced cost of material inputs and other production factors.

Packaging

Figure 11.58 presents the results of a 1992 survey conducted on behalf of the National Task Force on Packaging. The consumption or use of packaging by various manufacturing sectors is indicated by the bars, which also illustrate the relative proportions of packaging reused, recycled, and disposed of (disposal here being defined as consumption less amounts reused and recycled). The consumption and disposal data refer to packaging associated with the consumption of a particular sector's products as opposed to the packaging consumed during the process of manufacturing. For example, if a consumer were to dispose of a tube of toothpaste or the box containing a toaster, the statistic would be attributed to the relevant manufacturing sector. Each sector directly reports reuse and recycling data.

On the basis of the survey, which included the retail, wholesale, and manufacturing sectors, it was estimated that packaging waste sent for disposal decreased from 5.4 million tonnes in 1988 to 4.2 million tonnes in 1992 — a reduction of 21% (CCME 1994). This decrease met the National Packaging Protocol's target of reducing the amount of waste sent for disposal by 20% between 1988 and 1992. The survey also indicated that, for manufacturing as a whole, more material was reused (35%) than recycled (24%) and that the amount disposed of was 41% of the total amount consumed. Packaging statistics for individual industries vary owing to differences in such factors as the type of prod-

Table 11.36

Estimates of the composition of wastes generated by industrial sectors in Ontario

	% of industry total								
Industry	OCC[a]	Paper[b]	Wood	Glass	Plastic	Organics	Metal	Tires	Other
Food and beverages	4.4	4.5	2.0	8.6	2.0	60.6	5.1	0.0	12.8
Rubber, plastic, and leather products	9.6	2.1	18.1	0.0	18.8	0.0	5.8	31.4	14.3
Textiles and clothing	1.0	18.5	1.7	0.0	8.8	0.0	1.3	0.0	68.8
Wood	3.5	0.0	65.8	0.1	5.7	0.0	1.5	0.0	23.4
Furniture and fixtures	6.7	0.8	15.2	0.0	0.0	0.0	6.0	0.0	71.3
Printing and publishing	1.8	86.9	2.7	0.0	0.2	0.0	0.2	0.0	8.2
Metal fabricating	4.6	11.6	11.7	0.0	1.1	0.0	48.5	0.0	22.5
Machinery	5.4	1.5	11.4	0.0	3.5	2.7	23.9	0.0	51.6
Transportation	4.7	1.9	12.0	0.4	0.0	0.2	29.3	0.0	51.4
Electrical products	12.3	35.8	38.8	0.0	4.1	0.0	7.5	0.0	1.5
Nonmetallic mineral products	1.7	4.0	3.5	0.0	0.0	0.0	65.4	0.0	25.4
Chemical products	47.7	13.0	1.4	3.0	8.9	0.2	5.0	0.0	20.7
Other manufacturing	18.5	32.1	6.5	1.2	0.8	0.2	21.0	0.0	19.8

Notes: These estimates do not include the following materials: foundry sand, fly ash, blast furnace slag, compost, sewage sludge, bottom ash. These estimates are based on data from 180 companies in the Essex–Windsor (Ontario) area supplemented by data from Cornwall, Ontario; Seattle, Washington; and Brattleboro, Vermont.

[a] Other corrugated cardboard.

[b] Includes office paper.

Source: Ontario Ministry of the Environment (1991).

uct being packaged, packaging material used, the extent of packaging reduction that has already taken place, facilities for recycling, and markets for recycled materials. The high reuse rate for the brewery sector, for example, is due to the use of glass containers and the deposit return system for beverage containers (National Task Force on Packaging 1992).

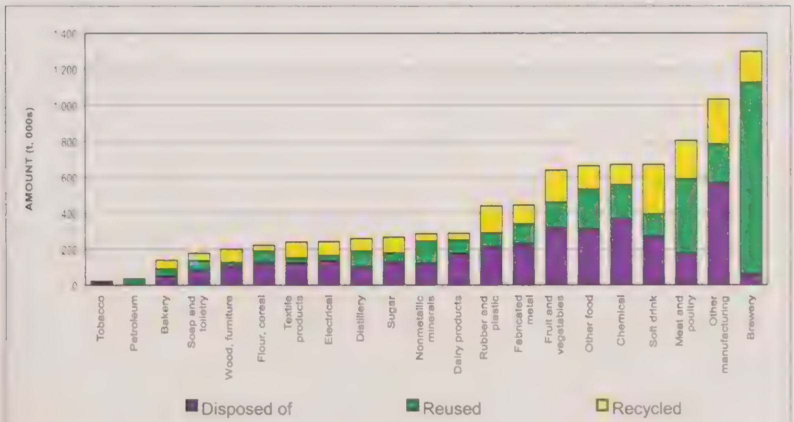
Industry's role with respect to meeting future targets of the Protocol — a 35% diversion of packaging from the waste stream by 1996 and a 50% diversion by 2000 — include reducing the amount of packaging used in the first place, increasing the reusability of packaging, and increasing the recyclability of new packaging.

Hazardous waste

Hazardous wastes — those that pose threats to living organisms, including humans — require special disposal techniques to render them harmless or less dangerous. Manufacturing processes are significant producers of hazardous wastes, which may be toxic, flammable, corrosive, explosive, or highly reactive. As Figure 11.59 reveals, 4 of the top 10 hazardous waste producers in Canada in 1991 were manufacturing activities — fabricated metal products, transportation equipment, leather and allied products, and chemicals and chemical products. Materials that are harmful or may contain harmful substances include acids, alkalis, solvents, resins, paint, oils, and sludge. These materials can arise from the manufacturing process and the transformation of raw materials, or they may be the residue of sanitary and pollution control techniques (such as contaminants removed from effluent streams). Table 11.37 lists some of the hazardous wastes produced by selected manufacturing processes.

Because of the potential risks involved, special management of hazardous wastes is required. Organic wastes are usually destroyed or neutralized. Inorganic wastes are usually concentrated, solidified, and disposed of in a secure facility. Techniques of neutralization, destruction, and disposal include incineration, landfill, filtration, and biological and chemical processes such as the use of microorganisms that can degrade waste oils. Apart from these techniques, which deal with hazardous substances after their creation, manufacturers can also use material substitution and process changes to reduce or eliminate the production of hazardous substances. Nevertheless, because of the expanding complexity and diversity of material inputs, production processes, and their resultant outputs (including wastes), the management of risk associated with the use and production of hazardous substances is itself becoming more complex. "The inevitable result," according to the OECD (1991), "is a growing uncertainty as to the risks involved; increasingly rarely will risk management simply take the form of an outright elimination of risks" (see Chapter 13 for more detail on hazardous waste).

Figure 11.58
Packaging disposed of, reused, and recycled, by manufacturing sector, 1992



Source: National Packaging Monitoring System (NPMS).

Towards sustainability

The increased effort on the part of manufacturers to mitigate the environmental effects of their activities, primarily through end-of-pipe solutions, is reflected in their expenditures on pollution abatement and control. A recent Statistics Canada survey of these expenditures revealed that they have been increasing both in absolute terms and as a percentage of total investment (Gaston 1993). As a percentage of capital expenditure, investment in pollution abatement and control rose from 0.7% in 1985 to 2.1% in 1990. These expenditures in 1989 amounted to over $1 billion. These figures do not account for expenditures not defined as pollution abatement and control but that, nonetheless, reduce an industry's impact on the environment. Changes that increase the economic efficiency of a production process, for example, often reduce environmental impacts. However, these other expenditures are more difficult to categorize.

Despite these encouraging trends, end-of-pipe solutions have been increasingly criticized as being merely provisional: "Clearly, if industry is to provide for today's and tomorrow's needs without undue environmental degradation — the goal of sustainable development — new processes will be needed that use less virgin material, produce markedly less pollution or waste per unit of product, and minimize environmental effects. Another consideration critical to sustainable development is the overall 'metabolism' of industrial activity; this includes the products industry creates and their ultimate use and disposal" (World Resources Institute 1994).

How is industry, and society in general, to carry out this momentous task of moving towards long-term sustainability? One way is through "green design," which is primarily an attitudinal or philosophical approach underlying a host of concepts and methods. Traditional design and production emphasize the economic dimensions of production. Development was shaped in large part by earlier perceptions that natural resources and the natural environment's ability to absorb wastes were unlimited, an outlook that has often been characterized as a "frontier mentality." Green design transcends the limitations inherent in this traditional approach and aims to minimize environmental impacts in terms of both resource consumption and pollution. Thus, it approaches the problem of product design and manufacture conscious of the limited capacity of the ecosphere to absorb the effects of human activities.

Life cycle assessment

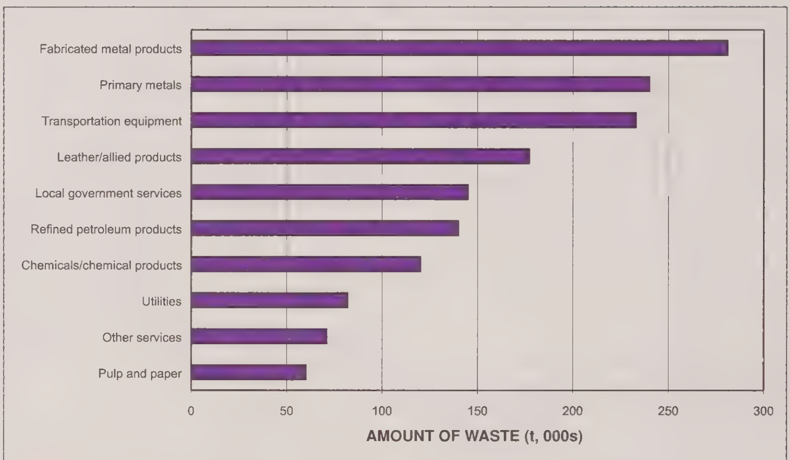
The Environmental Choice^{M} Program, Environment Canada's leadership labelling program, uses a life cycle approach in setting guidelines for products and services that are less stressful to the environment (Brady and Patenaude 1994). It is a holistic approach that recognizes that "all life-cycle stages (extracting and processing raw materials, manufacturing, transportation and distribution, use/reuse, and recycling and waste management) have environmental and economic impacts" (Environment Canada 1995g). Life cycle assessment is not restricted to the development of new products, as it may also be applied to proposed changes to an existing product's design or manufacturing process.

Life cycle assessment is used by Environment Canada's Environmental Choice^{M} Program to set guidelines for products when awarding the EcoLogo^{M} in its environmental leadership labelling program (Brady and Patenaude 1994). Life cycle information is used to identify areas where the key environmental impacts occur and to provide insights as to where changes in product composition, production processes, and other factors will be most effective in reducing these impacts. Products meeting program guidelines can qualify for the EcoLogo^{M}, thereby providing a market incentive to improve products and processes in terms of environmental impacts. Guidelines have been developed for over 40 products and service categories, including paints, paper products, automotive fuels and engine oils, insulation products, printing services, and general purpose cleaners.

The range of raw materials, energy sources, processes, plant locations, and other production considerations, coupled with factors such as transportation, consumer use, and postconsumer management, combine to make life cycle analysis

Figure 11.59

Hazardous waste generation estimates, by sector, 1991



Source: CCME (1995b).

Table 11.37

Selected hazardous waste streams

Substance	Description/example	Manufacturing activity
Heavy metal solutions and residuals	Spent plating or etching; rinses and other aqueous solutions; sludges from plating/etching lines or from treatment of solutions containing metals	Tanning leather products; chemical production; transportation equipment manufacturing; metal fabrication
Solvents and organic solutions	Halogenated, nonhalogenated, and mixed	Transportation equipment; chemical products
Sludges and inorganic residues	Ash; spent catalyst	Fabricated metals; transportation equipment
Organic and oily residues	Leaded and unleaded gasoline	Transportation equipment

Source: CCME (1995b).

a daunting task, however. Collecting data for all these different facets is difficult and is further complicated by the lack of scientific certainty about many aspects of human interaction with the environment. Initiatives designed to overcome such limitations include the development of a Canadian raw materials database by Environment Canada, the Canadian Standards Association, and the raw materials industry. The database will "quantify all energy and raw material inputs and environmental releases for the first two lifecycle stages: raw materials acquisition and primary processing" (Environment Canada 1995g). The purpose of the database is to provide environmental information that will help small and medium-sized businesses make internal improvements to production and other processes that affect the environment. The database will also provide the participating industries with benchmark data to use as a basis for making such improvements.

There are also trade-offs between traditional design criteria (e.g., appearance, packaging for freshness and longevity, and durability) and environmental criteria (e.g., recyclability and biodegradability). Trade-offs between different environmental goals may also have to be made. Debate may arise, for example, as to whether one environmental impact may be better or worse than another, as in the case where a new production process generates less solid waste than an older process but creates more air pollution (Curran 1993).

Industrial ecology

Ecology is the study of the relationships among organisms, including humans, and their environment. It reveals that there is a constant flow of energy in ecosystems and a constant recycling of matter. There is no such thing as waste: one organism's by-product becomes the raw material for another. Industrial ecology is an attempt to mimic the structure and functioning of ecosystems in the organization of industrial production.

Industrial ecology has been defined as "the network of all industrial processes as they may interact with each other and live off each other, not only in the economic sense, but also in the sense of direct use of each other's material and energy wastes and products" (Ausubel 1992). The Canadian cement industry provides a functional example of how these concepts can be applied (Canadian Cement Council 1994). The raw materials of cement — limestone, shale, and clay — are crushed, mixed, and heated in a kiln. These kilns have traditionally used fossil fuels (coal, oil, and natural gas) as an energy source. However, their unique characteristics allow the use of supplementary fuels derived primarily from hazardous waste, which may include spent solvents, organic sludge, paints, used oils, and inorganic materials. Raw materials used in the manufacture of cement may also be derived from wastes such as fly ash, foundry sand, spent catalyst, slag, lime sludge, and tailings containing alumina. The Canadian cement industry recognizes that the potential exists to replace up to 15% of its current thermal energy requirements with waste-derived fuel by the year 2000 and as much as 25% by the year 2010.

In Kalundborg, Denmark, industrial ecology has been applied on a wider scale. Energy and wastes are recycled at a complex that consists of an electric power generating plant, cement producers, an oil refinery, a plasterboard factory, a biotechnology production plant, heating utilities, and agricultural and horticultural operations (Fig. 11.60). For example, waste energy in the form of steam is released by the power station and used by the biotechnology company and the refinery. Similarly, gypsum, fly ash, and other waste materials are used by the cement and gypsum wallboard manufacturers (Tibbs 1992).

Burnside Industrial Park in Dartmouth, Nova Scotia, is being studied in an attempt to apply the industrial ecology concept on a much larger scale. The industrial park contains approximately 1 200 businesses and plants. A survey of nearly 300 of these revealed that only 14 used recycled material and only a third practised energy conservation. According to the study, managers did not realize that they were wasting energy (in the form of heat) and materials such as propellants, solvents, and discarded packaging. On the basis of these observations, Burnside Industrial Park was deemed an ideal location for designing an industrial ecosystem (Allen 1994).

Actions contributing to sustainable development

Policies to mitigate the environmental effects of manufacturing fall into three broad categories: voluntary action, regulation, and economic instruments. These approaches are not mutually exclusive; rather, to realize the goal of sustainable development, they should be mutually supportive.

Voluntary action

Voluntary initiatives are actions by individual firms or industrial sectors that are undertaken without reference to a legislative base. Such initiatives are also often led by governments. The advantages of voluntary programs are that they can be more cost-effective and lead to continuous improvement, allow flexibility in identifying goals and strategies, and allow swifter implementation of pollution prevention and control plans.

A pioneering example of voluntary action is 3M Corporation's Pollution Prevention Pays program, which was initiated in 1975. Between 1975 and 1989, pollution was halved for each unit of production, resulting in a cost saving of $500 million. In Ontario, a 3M tape manufacturing facility reduced its waste output from 2 800 t per year to 115 t, with annual savings of $1 million (Environment Canada and Industry Canada 1994).

A further example is the Responsible Care® initiative of the Canadian Chemical Producers' Association. This initiative guides the management of chemicals from "cradle to grave" — in other words, from research and development to use and disposal. It reports on the member companies' emissions of chemical substances to air, water, and land and on their emission reduction projections (Canadian Chemical Producers' Association 1994). In 1993, the association listed 306 chemical substances that it considered to be significant from either a human health or environmental

perspective: 178 substances listed in Environment Canada's National Pollutant Release Inventory, 50 additional substances that the association considers significant from either a human health or environmental perspective, as well as 78 substances listed by the ARET program that were not found on either the National Pollutant Release Inventory or the Canadian Chemical Producers' Association lists. The association projects a 72% reduction in total emissions by 1999 based on 1992 emissions (Canadian Chemical Producers' Association 1994).

The ARET program is a voluntary initiative conducted in partnership with government and coordinated by Environment Canada (see also the "Minerals, metals, and mining" component and Chapter 13). It is Canada's largest multistakeholder initiative and includes representatives from industry, health, and professional associations as well as from federal and provincial departments. ARET is based on a prioritized list of 117 toxic substances, only 13 of which are regulated in any way. Less than two years after ARET issued its challenge to industry to reduce emissions of persistent, bioaccumulative toxic substances by 90% and other toxic substances by 50% by the year 2000, over 260 organizations had responded (T. Stone, ARET Secretariat, Environmental Protection Service, Environment Canada, personal communication).

Further examples include the Canadian Manufacturers' Association's Improving Manufacturing Environmental Performance Program, designed for small and medium-sized businesses, and the Memorandum of Understanding signed by Environment Canada, the Ontario Ministry of Environment and Energy, and the Motor Vehicle Manufacturers' Association for the implementation of pollution reduction plans in the auto industry (Environment Canada 1993d).

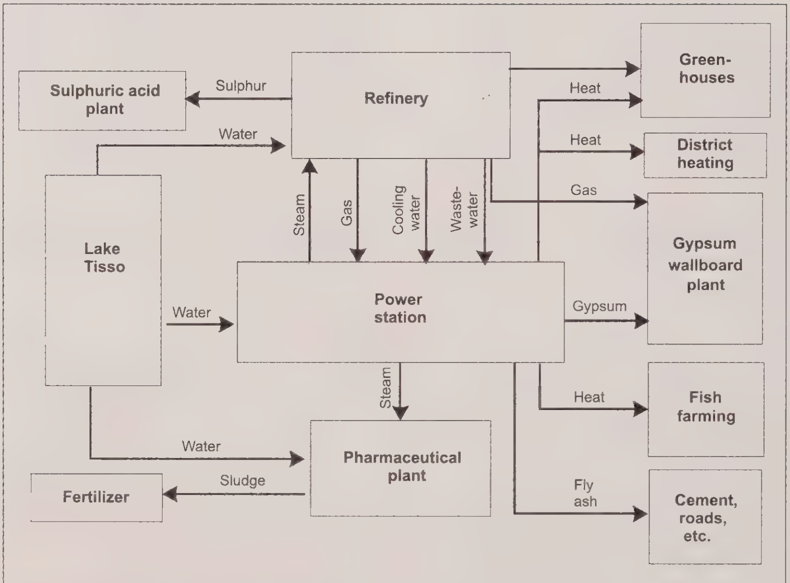
In February 1995, Canadian ministers of energy and environment agreed to adopt the Climate Change Voluntary Challenge and Registry Program as a key element of Canada's National Action Program on Climate Change. The Voluntary Challenge and Registry Program calls for companies and institutions to register their intent to limit greenhouse gas emissions by taking actions domestically and in any other country that is a Party to the United Nations Framework Convention on Climate Change. Initial engagement has been impressive. As of November 1995, over 475 companies and organizations representing the majority of greenhouse gas emissions in Canada had committed to participate in the program. Coverage in the manufacturing sector ranges from 95% of total chemical sector emissions to 50% of total pulp and paper sector emissions.

At the international level, the voluntary ISO 14000 standards have been developed by the International Organization for Standardization (ISO) to provide industries with a structure to manage environmental impacts. The standards cover a broad range of environmental disciplines, including basic environmental management systems, auditing, environmental performance evaluation, labelling, and life cycle assessment. The standards offer firms a management system that will help them assess their environmental credentials and make improvements where necessary. See Chapter 13 for more detail on the ARET and ISO 14000 programs.

Legislation

Traditionally, governments have attempted to control environmental degradation through legislation. This involves the setting of standards for environmental quality and the regulation of the use and disposal of certain hazardous substances. Compliance is monitored, and, in the event of noncompliance, fines and other sanctions are applied. As public environmental consciousness has increased, particularly with respect to pollution, and as the results of decades of environmental mismanagement have become increasingly manifest, the use of regulations has increased. Regulation has also been motivated by the proliferation of chemicals in Canada, of which over 35 000 different types are now estimated to be in use (Environment Canada 1993e).

Figure 11.60
The industrial ecosystem at Kalundborg, Denmark



Source: Tibbs (1992).

CEPA includes prohibitions on the manufacture and use of carbon tetrachloride, methyl chloroform, and certain other substances. The act is now under review, and one of the aims of the revision is to incorporate strategies of pollution prevention as opposed to pollution control.

One advantage of regulation is the establishment of uniform targets for all industries, thus creating a "level playing field." A major disadvantage, however, is that these standards may create undue burdens on certain industries. Because of differences in manufacturing processes, some industries may require more fundamental changes than others. Further disadvantages include the inertia associated with bureaucracy and the lack of incentives for industries to perform beyond the established standard.

Economic instruments

The principle behind economic instruments is to assume "those external environmental costs that are usually not taken into consideration in the cost–benefit analyses on which investment decisions are based" (Tolba et al. 1992). In other words, certain economic incentives exist that will encourage firms to avoid practices that degrade the environment. Four main classes of economic instruments have been identified (OECD 1991; Stavins and Whitehead 1992; Barde and Opschoor 1994):

- *Marketable permits*, which are polluting quotas, permits, or ceilings and which can be bought, sold, and traded. Pollution permits, for example, allow a firm to pollute to a certain percentage of an overall level of allowable pollution. If the firm can keep its pollution below its allowable level, it can sell or trade the remainder of its allowance to other polluters.
- *Charges*, which are applied to emissions to air, water, and land to discourage pollution.
- *Product taxes*, which raise the price of fertilizers, packaging materials, and certain other polluting products. Taxes of this kind act as a disincentive to the purchase of these products and as an incentive to making them more environmentally friendly.
- *Deposit refund schemes*, which encourage the reuse and recycling of, for example, packaging and containers.

Procurement policies, whereby large organizations such as governments purchase only "environmentally benign" products and services, constitute a further economic instrument. However, other than deposit refund schemes and the limited use of procurement policies, there has been little application to date of economic instruments in Canada.

Environmental industries

Increased concern about the effects of human activities on the environment has resulted in the emergence of an economic sector oriented towards eliminating or minimizing those effects. Environmental industries may be defined as those that design, develop, instal, or operate technologies, processes, products, and services to address environmental problems. These activities may be applied to any stage of a product's life cycle — from its initial design to its production, or to the management of the waste associated with it.

Industry, Science and Technology Canada (1990) identified four categories of goods and services representative of environmental industries:

- technology, products, and services developed specifically for environmental use (e.g., environmental impact studies, laboratory services, air monitoring equipment, aeration tanks, and pollution abatement technologies, such as flue gas desulphurization);
- multipurpose technology, products, and services that constitute a significant part of the cost of meeting environmental standards (e.g., general engineering and construction services, water pumps, solid waste pumps, holding tanks, piping, and valves);
- processes that mitigate an industry's environmental impacts (e.g., closed-loop water systems, high-efficiency burners, fuel-efficient engines, and electric arc furnaces); and
- consumer products and services that reduce environmentally harmful contaminant emissions or production of wastes (e.g., refillable plastic containers, reusable skids and packaging, recycled paper, lead-free gasoline, and reusable bottles).

The primary reason cited for the growth of environmental industries is government legislation (Industry, Science and Technology Canada 1990). More stringent guidelines with respect to the quality of environmental media and more stringent regulations for the emission and discharge of harmful substances have fostered the development of goods and services to meet these requirements.

Ontario's Municipal/Industrial Strategy for Abatement (MISA) is an example of the type of regulatory initiative that has provided an incentive to environmental industries. Implemented to identify and reduce the pollutants discharged from industrial and municipal sources into Ontario's lakes and rivers, MISA originally targeted nine industrial sectors, including petroleum refining, pulp and paper, chemical manufacturing, and iron and steel. A further 12 000 facilities currently discharging into municipal sewer systems are also to be regulated. The scale of such a program as well as the range of compliance expected from industries contribute significantly to the building of a market for environmental goods and services. Voluntary efforts on the part of industry, spurred by the realization that environmental efficiency and economic efficiency often go hand in hand, are also fuelling the expansion of the environmental sector.

The growth of the industry has been rapid. In Canada, there are an estimated 4 500 small and medium-sized firms, employing 150 000 people and generating revenues of $11 billion annually. Based on current growth rates of 5–7% annually, revenues are expected to reach $22 billion by the year 2000 (Industry Canada and Environment Canada 1994). Municipalities represent the largest markets for environmental industries, constituting approximately 40% of demand. The fact that many municipalities have no sewage facilities, the need to

upgrade existing facilities, and the need for increased solid waste management are cited as reasons for the size of this market and its growth. The pulp and paper, forestry, chemical, mining, utilities, and oil and gas industries also constitute significant markets.

Conclusion

Manufacturing is a vital component of the Canadian economy. Employment and exports are just two of its many benefits. However, because production processes exert pressures on the environment in the form of air and water pollution, energy and resource consumption, and waste generation, the economic benefits are accompanied by ecological costs, which are borne, in general, by society as a whole.

The requirements for sustainability as outlined in the World Conservation Strategy are the maintenance of life support systems, the preservation of biological diversity, and the maintenance of the productive capacity of species and ecosystems. These objectives may be used to assess the manufacturing sector's progress towards sustainability.

The manufacturing sector has achieved some success in mitigating its effects on life support systems — the phaseout of ozone-depleting substances, in keeping with Canada's commitment to the Montreal Protocol, being a prime example. Despite progress in this area, continued attention is required in others. The generation and disposal of hazardous wastes are a case in point. In 1990, 4 of the top 10 generators of hazardous waste in Canada were manufacturing sectors. These wastes constitute a direct threat to organisms and the environment and require special treatment and disposal to render them harmless or less dangerous.

In the interests of long-term sustainability and economic competitiveness, industry, government, and consumers are encouraged to change their actions with respect to such diverse activities as production, regulation and monitoring, and consumption. Pollution prevention, "green" design, resource recovery and recycling, the purchase of "environmentally" benign commodities, and the use of other economic instruments and incentives are some of the techniques currently used to meet World Conservation Strategy objectives. Manufacturers, governments, and consumers have all demonstrated initiative with respect to reducing the impacts of human activities on the natural environment and moving towards sustainability. The challenge for the future is to maintain the momentum.

Outdoor Recreation and Tourism

Introduction

Recreation and tourism have become major activities in Canada, which rank with agriculture, forestry, and other important sectors in terms of economic, sociocultural, and environmental importance. In 1992, Canadians took 97 million overnight trips, 55% to small city, town, rural, and wilderness destinations; 29% of them to big cities; and 16% outside Canada (Rogers 1995). Activity on such a scale obviously has substantial consequences for the environment, particularly in terms of transportation-related impacts, resource consumption, and disruption of wildlife habitat and natural ecosystems.

Whereas the economic significance of recreation and tourism is well documented, their social and their environmental significance are not. Indeed, monitoring and analysis of their social and environmental impacts are still in their infancy. However, there is a growing recognition within the recreation and tourism industry that environmental sustainability is not only a social responsibility but good business as well (see, for example, Buchanan 1994). A quality environment — with abundant wildlife, unspoiled landscapes, and clean air and water — is, after all, basic to Canada's appeal as a recreation and tourist destination.

Recreation and tourism are closely related activities, the main difference being that tourism involves travel away from one's home environment (defined in Canada as a radius of 80 km from a person's residence). Consequently, their impacts on the environment are largely similar, except for the obviously greater proportion of transportation-related impacts arising from tourist travel. The focus in this review will be mostly on activities that take place in rural or wilderness settings, as the marginal impact of recreational activities tends to be much greater there than in cities. In addition, the impact of tourism on the environment is easier to identify in rural areas than in cities, where contributions to environmental stress may come from a much larger number of sources. As Figure 11.61 shows, outdoor sports (such as golfing, skiing, hunting, fishing, hiking, snowmobiling, and numerous others) are the most popular category of activity in nonurban areas.

The following pages will present information on the economic and social benefits of these activities, provide an overview of the stresses on the natural environment, highlight some of the emerging developments in the sector, and discuss some of the initiatives that are now under way to enhance the long-term sustainability of outdoor recreation and tourism.

Economic and social aspects of outdoor recreation and tourism

National and international tourist visits contributed approximately $27.2 billion to the national economy in 1993 and generated over $12 billion in federal, provincial/territorial, and municipal government revenues. In 1994, tourism brought in some $10.036 billion in foreign exchange earnings, a value that was exceeded only by motor vehicles, motor vehicle parts, lumber, and business services. The tourism industry directly employs about 5% of the workforce and indirectly employs thousands more in all regions of the country (Government of Canada 1995b). As Figure 11.62 indicates, tourism has also been a leading creator of jobs.

In January 1995, the Canadian Tourism Commission was created with a mandate to provide a central forum for coordinating the development of tourism within Canada between the private and public sectors and

across all regions and levels of government. The creation of this commission was a recommendation of the Honourable Judd Buchanan in his October 1994 report to the Prime Minister (Buchanan 1994).

Tourism receipts are also an important component of the provincial economies, making up 7.4%, 5.6%, and 5.5% of the gross provincial product in Prince Edward Island, Nova Scotia, and British Columbia, respectively. Tourism receipts exceed 4% of the gross provincial product in all other provinces except Newfoundland.

Natural heritage and tourism
Outdoor recreation and tourism rely to a considerable extent upon mountains, forests, lakes, wildlife, and other aspects of Canada's natural heritage (Environment Canada 1993f). Table 11.38 provides estimates of some of the high 1992 participation rates by Canadian, American, and overseas travellers in tourism and recreation activities that depend on natural heritage. The leading trip was a visit to a national, provincial, or regional park. About 13.9 million such trips were made. The next most popular activity was swimming, which accounted for 9.7 million trips, followed by visits to zoos, museums, and natural exhibits at 8.3 million trips, and hunting or fishing at 6.8 million trips (Statistics Canada 1993d). Many of these activities involve a mix of outdoor, indoor, natural, and cultural elements. Examples are visits to museums, which link wildlife and archaeology, and parks, which link both natural and cultural experiences.

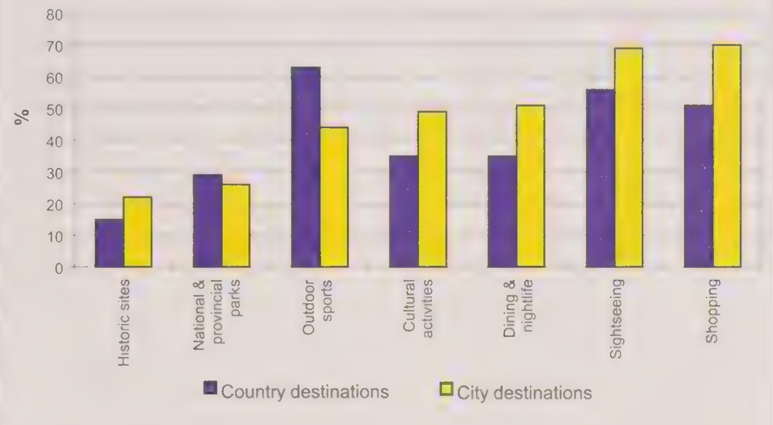
Spending on wildlife-related activities is a further indication of the importance of the environment to outdoor recreation and tourism. Wildlife-related expenditures by Canadians were estimated at $8.4 billion in 1991. Of this, nonconsumptive activities, such as sightseeing, bird-watching, and hiking, accounted for $4.4 billion, whereas the principal consumptive activities, recreational hunting and fishing, yielded a further $1.2 and $2.8 billion, respectively (Environment Canada 1994e). Table 11.39 summarizes these expenditures on a provincial basis.

Fishing is a particularly good example of a recreational activity that has close linkages to the environment and considerable importance economically. The scale of this activity is substantial. According to the 1990 Survey of Recreational Fishing, nearly 5 million Canadian and about 900 000 foreign anglers logged a total of 67 million fishing days and caught over 300 million fish. They spent an estimated $8.1 billion on goods and services directly associated with the sport, including $5.9 billion on package deals, accommodation, food, transportation, fishing supplies, and other related items, and a further $5.3 billion on boats, motors, camping equipment, special vehicles, and other durable goods (Department of Fisheries and Oceans 1994e).

All of this economic activity could not be supported, however, without a healthy environment. Of particular importance are water quality, lack of contaminants in fish, lack of angler crowding, the presence of favourite species (trout, smelt, Walleye, and perch), the size of the fish, the catch rate, and the natural beauty of the surroundings.

Between 1960 and 1994, Canada's protected area almost quadrupled, from 22.1 to

Figure 11.61
Recreational activities of Canadian tourists



Source: Adapted from Rogers (1995).

Figure 11.62
Employment growth rate, by industry sector, 1975–1988

Source: Statistics Canada (1993c); Canadian Tourism Commission impact model.

78.8 million hectares: 7.9% of the nation's total land and fresh water. Forested land is another natural asset that figures prominently as a tourist attraction. National data for participation in outdoor recreation on forested lands, however, are limited to provincial, territorial, and national parks and do not reflect the wide use of forested lands outside of these protected areas (Natural Resources Canada 1995a). Still, more than 50 million hectares, or 12% of Canada's forested land, are in protected areas, and recreational usage in some of these areas is substantial. In British Columbia, for example, about $2.4 billion was spent on recreational uses in provincial forests in 1993 — about 67% on road-accessed activities and 33% on roadless backcountry recreation (B.C. Ministry of Forests 1995). A more detailed discussion of protected areas is contained in the "Land" component of Chapter 10.

Outdoor recreation and tourism are also important for the social and cultural well-being and quality of life of Canadians. Many persons prefer to live in areas where scenery, water, wildlife, and other resources and associated recreational opportunities provide for a wide range of leisure activities. Canadians also value the opportunity to visit more distant parts of the country to enjoy natural resources and landscapes as part of Canada's natural heritage.

Stresses on outdoor recreation and tourism resources in Canada

The effects of outdoor recreation and tourism on wildlife, water, land, air, and other components of the ecosystem are wide-ranging. One attempt at summarizing these effects is shown in Table 11.40. The following discussion looks at a number of stresses on outdoor recreation and tourism in greater detail.

The dilemma of balancing recreational use with environmental sustainability is most evident in Canada's national and provincial parks, although it is by no means confined to them. The parks serve both a recreational and a protective purpose, but too many visitors may threaten the survival of the wildlife species (both plant and animal) the park is designed to protect. Consequently, parks may have to take mitigating action, such as controlling access and use, to remain sustainable.

Land

Recreational impacts on the land affect physical and biological resources. Soil and vegetation can be physically, biologically, and chemically altered along trails, in campsites, in grazed meadows, and in other intensively used areas. Plants can be damaged or killed, with a consequent reduction of the vegetation supply and alteration of the composition of biological communities.

Point Pelee National Park (Ontario), one of the best bird-watching locations in North America, is a classic example of a park where excessive numbers of visitors were threatening to surpass sustainable use levels and cause unacceptable degradation of resources. Pelee used to be overrun by automobiles, which were frequently backed up bumper to bumper and emitted large amounts of exhaust. Parking lots overflowed, and cars lining the roadsides in search of improvised parking spaces crushed plants or killed them with dripping oil and engine heat. Roadside vegetation gave way to trampled ground. Rare amphibians and reptiles became road-kill statistics. Away from the roadway, uncontrolled visitor pressure led to the deepening of foot trails, trampling of undergrowth, and damage to fragile nesting sites and scarce habitat.

Analysis of the various threats to Point Pelee led park managers to adopt a series of measures in an effort to establish more sustainable patterns of usage. Camping facilities were closed, and a public shuttle service was provided to ensure controlled access and to limit vehicular traffic, parking damage, and road-kills. Boardwalks were constructed along predetermined marsh routes to facilitate access and channel visitors away from sensitive areas, and a planned system of trails was built to improve visitor enjoyment and direct users along advantageous routes. Unused trails were scarified and the areas rehabilitated to give further protection to the park's flora and fauna. Person–visits to the park increased by 10%, from 410 000 to 450 000, between 1993 and 1994 (Department of Canadian Heritage 1995a).

Even where visitor intensity is relatively low, environmental effects can be severe. Because of its river and canyon orientation, the Nahanni National Park Reserve, for example, experiences concentrated visitor use along the narrow river corridor at sites such as Virginia Falls, Rabbit Kettle Hotsprings, and the main campsites.

Resource and land use conflicts, as well as associated environmental impacts, can also arise from outdoor recreation and tourism projects such as ski resorts and seasonal home subdivisions. Outdoor recreation and tourism activities may also conflict with each other. Ski and other facilities can produce noise and other

Table 11.38
Selected activities of Canadian, American, and overseas travellers, 1992

	Person–trips[a] (000s)			
Activity	Canada	U.S.	Overseas	Total
Visit zoo, museum, or natural display	4 165	2 856	1 275	8 296
Visit national, provincial, or regional park	8 385	3 993	1 528	13 906
Swimming	7 487	1 745	438	9 670
Other water sports	4 194	414	122	4 730
Hunting or fishing	5 653	1 084	103	6 840
Cross-country skiing	917	94	28	1 039
Downhill skiing	1 729	313	112	2 154

[a] Overnight trips of 80 km or more in length.

Source: Statistics Canada (1993d).

effects that damage or destroy opportunities for wilderness and nature tourists. Similarly, auto-touring can conflict with the wilderness experience of hikers, and hunters can adversely affect bird-watching and naturalist activities. Often these conflicts are not sufficiently recognized and planned for in land use decisions in areas important for recreation and tourism.

Water

Recreationists adversely affect water through residential sewage discharges and discharges of solid wastes and hydrocarbons from boats. There is a tendency for owners of lake or marine coastal cottages to construct breakwalls and other structures intended to reduce erosion and flooding by waves, currents, and normal shoreline processes. The introduction of such structures reduces access to the shore and may cause impacts such as siltation or erosion along other portions of the shoreline. Cottagers press governments to subsidize the costs for this protection as well as to pay for restoration and protection of roads, water supplies, and other services and resources subject to loss or pollution as a result of cottage development. These situations often arise because of inadequate understanding of how erosion, flooding, and other processes normally change shoreland, and because of difficulties in regulating land uses effectively in coastal as well as floodplain and other areas subject to flooding, erosion, and other hazards. The occurrence of the foregoing problems is widespread along the Lake Erie and Lake Huron shores.

As well as being a source of environmental stress, recreation and tourism themselves may undergo important changes as a result of environmental changes arising largely from other human activities. A prime example is the current growing concern about global warming and its potential effects on local climates, river flows, lake and ocean levels, and other aspects of the environment. Climate changes may occur over very large areas in the next several decades and could affect outdoor recreation and tourism in many locations in both positive and negative ways (Wall 1994). In contrast to expected increases in sea levels and associated large-scale drowning of many coastal areas, lower water levels are predicted for the Great Lakes largely as a result of higher evaporation rates. During low-water periods in the 1960s, water levels in the Great Lakes dropped a metre or more below the 100-year average, damaging cottage beaches and lake frontages and adversely affecting recreational boating, fishing, and other recreational activities (McBoyle et al. 1986).

Wildlife

Animals are adversely affected when recreationists disturb habitats or approach them too closely. Many of them are also killed by vehicles. The Bow River Valley Corridor in Banff National Park is an example of an area where such impacts have had serious effects on some wildlife populations. Facility construction, particularly trails, can affect biological resources

Table 11.39
Wildlife-related expenditures, by province, 1991

Province	Total expenditures ($, millions): Recreational hunting[b]		Primary nonconsumptive trips		All wildlife-related recreational activities	Average yearly expenditures ($) per participant[a]: Recreational hunting	Primary non-consumptive trips and other activities
Newfoundland	80	(63)	47	(37)	127	919	490
Prince Edward Island	3	(33)	6	(67)	9	516[c]	220
Nova Scotia	31	(28)	80	(72)	111	343	271
New Brunswick	50	(36)	87	(64)	137	567	583
Quebec	274	(27)	744	(73)	1 018	611	496
Ontario	325	(16)	1 696	(84)	2 021	780	486
Manitoba	44	(28)	114	(72)	159	663	417
Saskatchewan	49	(28)	124	(72)	173	660	654
Alberta	156	(19)	679	(81)	835	1 165[c]	1 126
British Columbia	174	(18)	803	(82)	977	1 319	967
Canada	1 187	(21)	4 380	(79)	5 568	769	619

Note: Figures may not add up owing to rounding.

[a] Based on Statistics Canada estimates of 1991 population 15 years of age and over.

[b] Percentages are given in parentheses.

[c] The sampling variability of this estimate is slightly higher than for other groups for reasons such as the small sample size on which the estimate was based and the degree of variation in the distribution of the characteristic measured.

Source: Environment Canada (1993f).

Table 11.40
Environmental effects of outdoor recreation and tourism

Impacts	Causes	Examples and/or location
Pollution		
Air	Motor traffic, production and use of energy	Lower Bow Valley corridor, Banff National Park
Water	Discharge of untreated wastewater due to absence or malfunction of sewage treatment plants Discharge of solid waste from pleasure boats Discharge of hydrocarbons from motor boats	Turkey Point Provincial Park, Ontario St. Lawrence River Great Lakes, other lakes and bays
Solid waste	Litter Absence or inadequacy of waste disposal facilities (mainly household waste)	e.g., picnic areas Frenchman's Bay near Toronto, Ontario
Noise	Increased traffic Certain recreational vehicles (e.g., snowmobiles, cross-country motorcycles, motor boats, airplanes) Tourism crowds and associated facilities for entertainment	Windsor–Quebec City corridor e.g., lakes with major cottage and resort developments Gatineau Hills area, Quebec
Loss of natural landscape and agricultural and pastoral lands		
Facilities and infrastructure	Housing and infrastructure for tourists and other users of open space and other lands	Riding Mountain National Park, Manitoba, and Rondeau Provincial Park, Ontario
Access	Access to beaches, forests, and natural sites is often blocked by new private owners	Muskoka area and other interior lakes in Ontario, Alberta, and British Columbia
Destruction of flora and fauna		
Human activities	Changes like those noted above, plus pollution may result in a decline or disappearance of local plants and animals	Fish, amphibian, and other declines along the Great Lakes
Tourist use and behaviour	Collection of fruits, plants, and animals and carelessness with fire can result in damage or destruction of plant and animal habitats and species themselves	National and provincial parks in the Atlantic provinces
Degradation of landscape		
Aesthetics	Aesthetic degradation of rural and urban landscapes, e.g., transmission lines, introduction of exotic species, new architectural and building styles	Lake Huron coast from Pinery Provincial Park to the Bruce Peninsula, Ontario
Quality of experience	Excessive numbers of visitors can result in a decline in desired quality of experience, e.g., on wilderness recreation or on historic or architectural sites	Ellesmere Island National Park Reserve, Northwest Territories, and use of wild and heritage rivers, such as Grand River, Ontario, or St. Croix River, New Brunswick
Congestion		
Scheduling and crowding	Time and space scheduling and crowding of visitors (e.g., holidays, weekends) can stress air, water, soils, and other aspects of the environment, damage these resources, and reduce the quality of life in the host areas	Kincardine on Lake Huron, and east coast beaches on Vancouver Island
Traffic	Traffic congestion leading to high fuel consumption, heavier air pollution, and safety hazards to wildlife and humans	Kootenay, Banff, Yoho, and other western national parks, and Fundy National Park, New Brunswick

Source: Adapted from Tolba et al. (1992).

as well. Impacts of people on vegetation have also been widely studied throughout Canada and mitigation measures taken, such as those at Point Pelee.

The effects of recreational activity on the migratory paths of animals require further investigation. Protection of species requires large parks with ecologically responsive boundaries. However, many animals have extensive migratory routes that cannot be encompassed within a single protected area (Wall 1994). In southern Alberta's Waterton Lakes National Park, for example, both Grizzly Bears and Wolves migrate outside the park boundaries, where they can be killed by vehicles or shot by ranchers protecting livestock and crops (McNamee 1989).

Parks as tourism and recreation destinations

Some parks, both national and provincial/territorial, are overused, particularly during peak seasons, as tourism and recreation destinations and attractions. Although the problem of overuse is not generalized, the issue is nevertheless significant. Parks are established for a variety of goals, such as protecting ecological integrity, creating recreational opportunities, and providing economic benefits from both tourism activities and direct use of park resources. The balance among these goals determines the sustainability of Canada's parks systems. In 1988, the Canadian Parliament amended the *National Parks Act* so that ecological integrity will be the first priority of park management. Thus, environmental quality in national parks cannot be allowed to decline as a result of tourist use.

Park visitors' satisfaction is more closely correlated with environmental quality, the adequacy of facilities and programs, and the fulfilment of expectations than use density or gross numbers (Graefe et al. 1984; Beaumont 1993). Thus, to maintain visitor satisfaction in crowded locales, protection of natural features must be assured, facilities must be capable of handling the numbers, programs must be high quality, and the visit expectations must be appropriate. Key approaches to the management of large numbers of visitors include abundant pretrip information, quality road transportation networks, scheduling of access, use limits, hardening of trails in sensitive areas, visitor training, and law enforcement (Eagles 1995).

Human activities and facilities, however, are exerting increasing pressure on Canada's parks. Numerous examples across the country illustrate the potential loss of park resources owing to growing tourism pressure. Banff National Park is a prime example on a large scale (see Box 11.19). Similarly, a multiplicity of service centres and resorts in Manitoba's Whiteshell Provincial Park threatens its value for backcountry pursuits. Increased access can adversely affect wildlife populations through disturbance of habitats and grazing lands.

Volume and variety of tourism can eventually diminish the appeal of a location, as in Ontario's Algonquin Provincial Park, where overcrowding had reduced the attraction of camping and canoeing in peak season. The Province of Ontario established a wilderness canoe use level for the interior of the park of approximately 200 000 visitor–nights per year. A sophisticated system of lakeside campsites, portages, information maps, computer registration, and entrance control implements the policy (Eagles 1995). Thus, a clearly defined balance is required to preserve the ecological integrity of a park while allowing sensitive use of its resources for both recreation and economic returns. That means recognizing and respecting limits. Authorities responsible for the West Coast Trail in British Columbia, for example, have avoided detrimental effects from a growing number of hikers by limiting numbers through a controlled reservation system.

Impacts of human activities: national parks as an example

There are national parks and reserves in each of Canada's 15 terrestrial ecozones. To identify stresses and assess the state of ecosystems in these existing parks and reserves, Parks Canada sent a questionnaire to officials of 34 national parks in 1992. A stress was considered significant if:

- it was having a definite ecological impact;
- it was having an impact upon an area greater than a local scale (1 km^2); and
- the trend in the intensity of the stress was either increasing or stable.

Twenty-two of the 34 parks reported that visitor and tourism facilities (both within and outside the parks) were causing a significant ecological impact. These facilities included roads, accommodation, golf courses, ski hills, and swimming pools, among others. New developments within national parks are tightly restricted, and these constraints are largely supported by public opinion. A 1993 Angus Reid survey indicated that 92% of Canadians felt that visitor access should be limited where necessary to protect the environment, and 88% of Canadians thought that development that threatens natural resources in the parks should be limited (Angus Reid Group, Inc. 1993). The survey also indicated that 93% of Canadians believe that Parks Canada should be more involved in protecting areas near national parks when activities in those areas threaten the parks' natural resources.

Many of the reported stresses simply confirm how connected protected areas are to the rest of the country. Nineteen parks have transportation or utility corridors, either electric lines and gas pipelines or through highways and railways. Many parks also reported impacts from forestry and agriculture. Riding Mountain National Park, for example, is surrounded by intensive agriculture, whereas logging occurs

immediately outside the borders of parks such as Fundy, Pukaskwa, Yoho, and Pacific Rim. Although these stresses occur outside the park boundaries, they are still within the regional ecosystems.

Some of the more traditional national park concerns, such as vehicle kills of wildlife, solid waste, and sewage, were reported from only four parks. These stresses come from sources primarily within park boundaries or are small in scale and have been successfully dealt with by park management, in contrast to larger regional issues. Figure 11.63 shows the number of parks reporting significant ecological impacts from human stresses. Of the 29 stresses identified, only 2 originated inside the parks. Stresses originating totally outside park boundaries numbered 4, whereas 23 stresses occurred without regard to boundaries.

On a spatial scale, the majority (52%) of these stresses were reported to be acting over an area greater than 100 km², whereas only 2% were on a local scale (less than 1 km²). Forty-three percent of stresses were reported to be increasing, whereas 12% were decreasing (Department of Canadian Heritage 1995b). The large spatial scale of these issues illustrates the need to consider management options on an ecosystem basis.

Sustainable development is an integral part of the Parks Canada guiding principles and operational policies (Department of Canadian Heritage 1994). Specific policies have been developed for national marine conservation areas, heritage rivers, national historic sites, historic canals, and other heritage resources to ensure protection, access, and use commensurate with their carrying capacity. Tourism is recognized in all these policies as a legitimate function to be managed in a sustainable manner (Consulting and Audit Canada 1992).

The current vision for national parks is one that recognizes the natural environment as worthy of preservation, independent of economic factors (Environment Canada 1987): "National parks and other protected places are our lifeline to an ecologically stable future. They are places where the forces that animate our planet and make it unique are allowed to operate with minimal interference by man; places where we can wonder and pay respect to other living things and the intricacies of ecosystems; places that produce oxygen, stabilize the hydrological cycle, grow abundant fish and wildlife, stay erosion, pour out no human-made toxicant into air or water. They are places where people can study the vital functions of nature, to understand better the potentially threaten-

Box 11.19
Banff National Park: balancing conservation with development

In November 1885, Canada established a 26-km² reserve at Banff to protect a large hot spring for visitor use. It soon became Canada's first national park, with the goal of balancing conservation with recreation and tourism. It is the second oldest national park in the world and a world-famous symbol of wilderness. With the three other national parks — Jasper, Kootenay, and Yoho — and three provincial parks that border it, it forms the Canadian Rocky Mountain Parks World Heritage Site. Over the past hundred years, however, conservation, use, and development within the park have not always been successfully balanced.

In the early 1900s, the park was expanded to over 10 360 km². Because of pressures for hydroelectric and other developments within the park boundaries, the area was subsequently reduced to its current 6 641 km².

Early days in Banff saw excesses of development. Both resident and tourist hunters greatly reduced populations of North American Elk and other animals both within and outside the park. Fish were killed using dynamite. Forests were burned and cut. The construction of roads and other facilities was encouraged, the Banff Springs Hotel and Chateau Lake Louise were built to draw tourists to the park, and the Banff–Radium and Banff–Jasper highways were built in the 1920s and 1930s.

In the 1950s, postwar prosperity and improved highways attracted tourists during the summer. In the late 1960s, ski facilities were developed, and Banff became a year-round recreation area. This brought with it the pressure for more development. In the 1980s and 1990s, the number of tourists and the pace of development have continued to expand. For example, between 1988–1989 and 1993–1994, the number of person-visits to Banff rose from 3.8 million to 4.3 million, an increase of 12%. The pressures of increasing numbers of visitors and increased development have raised questions about what national parks are for. Do they exist to preserve and protect ecosystems, or are they simply tourist attractions?

Although Banff National Park cannot be considered a pristine wilderness, only 2% of its area has been altered by development. It is the location of that development in the Bow Valley that has led to the conflict between continued preservation and development. The valley is critical habitat and an important travel corridor for wildlife. It is also an ideal location for development and contains highways, a railway, an airstrip, a golf course, three ski resorts, the village of Lake Louise, and the town of Banff. Large numbers of visitors at the townsite and in the Bow Valley corridor create highly concentrated environmental stresses and a continuing conflict between pressures to develop montane valley bottomlands and the desire to protect habitat and travel corridors for wildlife (see Chapter 3, Fig. 3.10).

In an attempt to resolve these conflicts, the minister responsible for Parks Canada appointed an arm's-length group, the Bow Valley Task Force, in mid-1994 to prepare a plan within two years for ecology-based management and sustainable tourism in the park's Bow Valley.

Source: Corbett (1994); Department of Canadian Heritage (1995b).

ing human impacts elsewhere. They do not impede our future. They anchor it. They are not a repudiation of economic development. They balance it."

Managing the environmental effects

As tourist numbers increase and the variety of recreational types and technologies expands, environmental stresses on tourist areas will intensify. To address this problem, it is necessary to consider the concept of carrying capacity.

Carrying capacity is based on the belief that a given environment has the ability to sustain activities up to a certain point, beyond which some form of environmental and/or activity deterioration can be expected. The tourism industry defines carrying capacity as "the maximum number of people who can use a site without an unacceptable alteration in the physical environment and without an unacceptable decline in the quality of experience gained by visitors" (Mandziuk 1995).

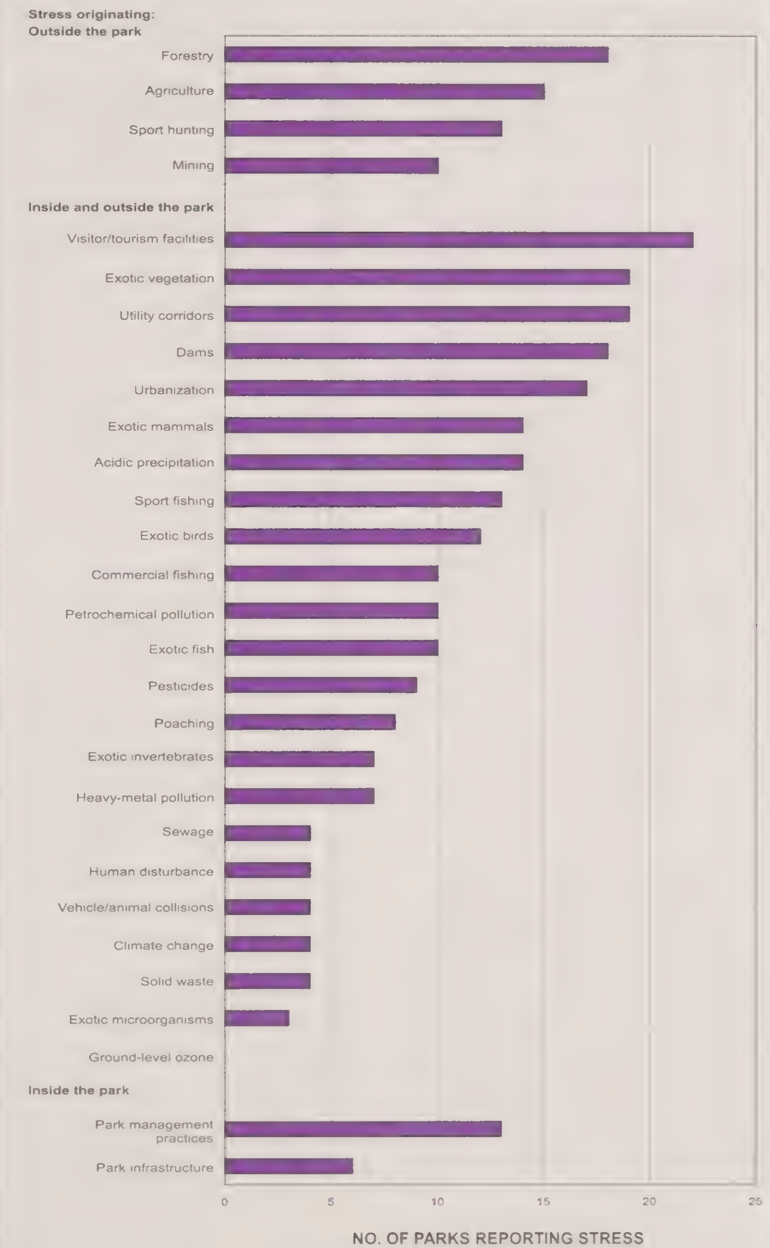
The factors involved in carrying capacity measurement fall into the following categories:

- *ecological*: tourists' impact on flora and fauna;
- *physical*: capacity of trail surface, sewer systems, lodgings, etc.;
- *psychological*: effect of overcrowding on visitors' experience;
- *social*: host peoples' tolerance of increased tourism;
- *management*: level of economic resources, trained personnel, etc.; and
- *economic*: ability to absorb tourist functions without squeezing out desirable local economic activities (Mandziuk 1995).

Determining an area's carrying capacity for tourism and evaluating the importance of different resources can be complicated by several factors. These include differences in the rate at which various impacts occur, differences in the types of impacts that arise from various activities, and differences in the sensitivity of various envi-

Figure 11.63

Number of national parks reporting significant ecological impacts from various human stresses



Note: 34 national parks were surveyed.

Source: Department of Canadian Heritage (1995b).

ronments to different types and levels of usage (Manning and Dougherty 1995).

Related to regional recreational features and opportunities, the assessment of carrying capacity helps to define the limits of acceptable change and the approach to management. British Columbia has addressed these issues in its 1994 Protected Areas Strategy (Peepre and Associates 1993).

The idea of a tourism cycle is another useful concept for understanding, anticipating, and planning the development of outdoor recreation and tourism and its effects (Fig. 11.64). The idea of the cycle does not necessarily apply everywhere, however. Typically, as a site is discovered and developed, tourists increase in numbers and kind, as do the resources and facilities used for a growing range of recreation opportunities and tourism developments. More and more settlement occurs, and beaches, dunes, plants, animals, wetlands, water, and other resources tend to be modified or replaced by dredged and filled beaches, marinas, swimming pools, and other new resources and facilities. These changes, in turn, promote new and more activities, such as high-speed boating, waterskiing, and sunbathing, the expansion of hotels and roads, greater water use and pollution, and other changes detrimental to resource conservation and environmental quality.

Eventually, an area can become so developed and changed that its initial environmental attractions are no longer present, and the area enters a period of decline and adjustment. Wasaga Beach on Georgian Bay and Turkey Point on Lake Erie are good examples of this process in Ontario. Both suffer from damage and destruction to vegetation, wild animals, biodiversity, dunes and beaches, and water quality. Both are highly developed with cottages. Access to the beach is difficult for visitors. Erosion and flooding are often experienced by cottagers. Crowding and other impacts are encountered frequently on holidays and weekends. In this respect, large parts of the shorelines of lakes such as Lake Okanagan in British Columbia and lakes Erie and Huron in Ontario have been developed more or less incrementally for tourism and related uses in the last few decades.

Emerging developments and future directions

Increasing concern about the sociocultural and environmental effects of large-scale tourism and recreational development has led to a growing interest in a range of interrelated ideas for reducing these effects. One that is receiving growing attention in both tourism industry and government initiatives is ecotourism, which combines nature, adventure, and cultural experiences in a countryside setting (HLA Consultants and The ARA Consulting Group Inc. 1994).

The idea of ecotourism is, in fact, an old one. It took on its modern manifestation in the late 1960s and 1970s, at a time when growing concern about the increasing effects of economic growth on water quality, wildlife, forests, and other aspects of the environment resulted in the introduction of the concept of ecodevelopment. This term referred to types of economic development that took plants, animals, soils, and other environmental processes and patterns into account when deciding on the kind, location, size, intensity, and other characteristics of land use changes.

Hawkes and Williams (1993) have investigated and reported upon some illustrative examples of ecotourism. The Saguenay Marine Park along the St. Lawrence River in Quebec, for example, is promoting land-based whale watching as an activity that does not harm sensitive Beluga habitat. Waterfowl, fish, and other resources are to be cooperatively managed by government representatives, tour boat operators, naturalists, recreationists, and other members of the community. Similarly, Yukon tour operators are now working on ways to minimize environmental and cultural impacts on northern landscapes while maximizing the local economic benefits of tourism.

A further ecotourism initiative is the Trail of the Great Bear, designed to link the United States' Yellowstone National Park and Waterton–Glacier International Peace Park and Canada's Banff National Park, as well as a range of other protected lands and forests in both nations. The idea for the trail originated in 1985 as a means of promoting natural and cultural park values and drawing visitors to communities and sites adjacent to park boundaries. A comprehensive guide book for the trail has been developed, and joint venture projects aimed at the whole trail, as well as individual endeavours, were begun in 1991–1992.

In British Columbia, ships are used for educational wilderness trips to coastal areas, such as the Queen Charlotte (Haida Gwaii) Islands. However, ecotourism can also be an environmentally and culturally disruptive force, as tourist activities expand into more remote areas. With the end of the Cold War, for example, the circumpolar region has opened up, and cruise ships are now a concern in the Arctic. In 1984, the first cruise ship visited the Northwest Passage; in 1995, five ships visited. In Alaska, the number of cruise ships has increased 100-fold since 1957. In 1995, one operator, Princess Cruises, pulled out its ships from Alaska for fear of disrupting Aboriginal communities.

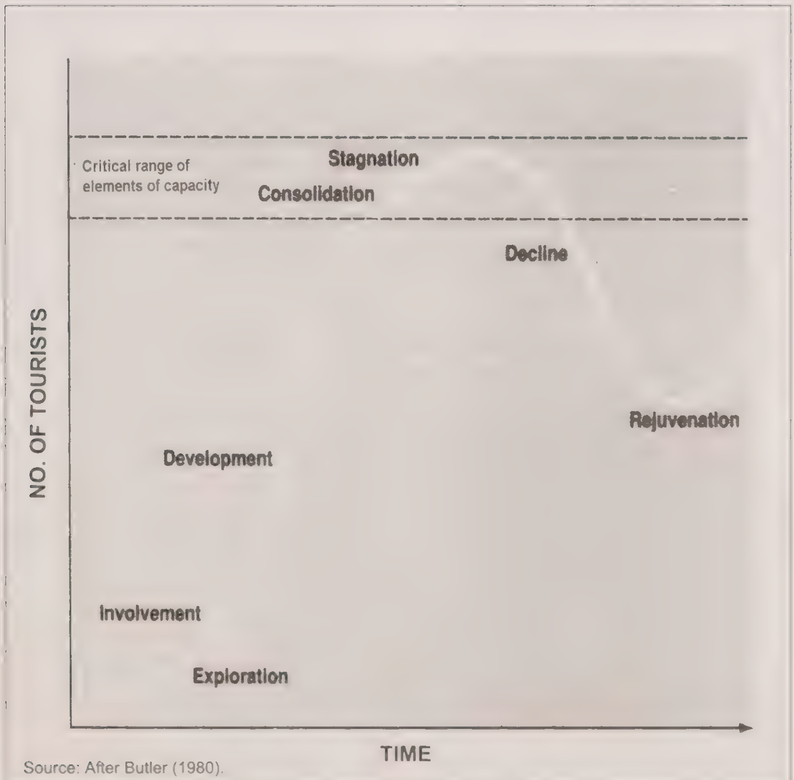
If expansion by green or ecotourism enterprises continues in future decades, it seems unlikely that many areas can be sustained in the wild state, unless planning and management arrangements and other forces at work are modified in some fundamental ways. Fortunately, hotels, resorts, other large-scale tourism developments, and airlines are becoming more ecologically sensitive in various regions of Canada, and several of them have launched environmental programs.

Sound market research identifying ecotourists and their needs and expectations is extremely limited. However, a study for Alberta and British Columbia (HLA Consultants and The ARA Consulting Group Inc. 1994) concluded that the opportunity for ecotourism in the two provinces was substantial, with as many as 1.6–3.2 million potential ecotourists in seven major metropolitan markets alone (Seattle, San Francisco, Los Angeles, Dallas, Chicago, Toronto, and Winnipeg).

In addition to determining existing and potential ecotourism demand and advising government and industry on how to respond, the study examined the relative importance of parks and protected areas to the ecotourism traveller. Parks and protected areas rated very highly in importance, as they provide locations in relatively natural settings where ecotourists can enjoy many activities. Of 15 rated factors, ecotourists rated parks fourth. In addition, the other top-rated factors (casual walking, wildlife viewing, learning about other cultures, wilderness setting, and hiking/trekking) are all activities for which parks and protected areas are ideal settings. The study results indicated that although interest in winter ecotourism is considerably lower than interest in ecotourism for the summer months, it is nevertheless significant enough to warrant the provision of opportunities. Because of their year-round operation, parks are attractive locations for many of these activities, especially as most private operators in more remote areas outside parks cannot maintain viable winter operations. This situation may change with more market interest and awareness and more effective promotion.

An offshoot of ecotourism is adventure travel, an outdoor leisure activity that generally occurs in an unusual, exotic, remote, or wilderness setting and involves an unconventional means of transportation and possibly (though not necessarily) high levels of physical activity. The most popular adventure travel activities in 1993 were, in order of popularity, trail riding, canoeing, nature observation, snowmobiling, and whale watching. Estimated revenues for adventure travel in 1993 were $165.1 million, a 12.9% increase over 1992 (Tourism Canada 1995).

Figure 11.64
Tourist area cycle of evolution



Source: After Butler (1980).

The development of rural tourism also has significant implications for the environment. According to a recent study of cultural tourism and outdoor recreation in Ontario (Reid et al. 1993):

- Rural tourism/visitation provides an opportunity to contribute purposefully to community development and to achieve social, economic, and environmental sustainability. Most importantly, rural tourism/visitation relies on existing infrastructure — farms, agrarian landscapes, human, built, and natural heritage resources, and rural events and attractions — and requires relatively little in the way of major investments or physical change. It is compatible with existing rural life and the need to effect a slow transition to new roles for Ontario's rural areas.
- Approximately half of tourism expenditures made in Ontario in 1991 ($4.5 billion) were made in rural Ontario. Studies indicate that of the 50 million person–trips (1991) made into rural Ontario, most were for recreation and pleasure or for visiting friends and relatives.
- The vast majority (76%) of Ontario's accommodation businesses are located in rural areas. Virtually all campgrounds and summer camps are rurally based, as are three-quarters of all bed and breakfast establishments.

Another concept that has been introduced to promote more environmentally and socially sensitive tourism development has been termed "sustainable tourism development." This concept is now being applied to national and territorial park operations, such as Auyuittuq National Park Reserve and Ivvavik National Park in Canada's North, and aims to combine conservation of resources and environmental protection with economic activities and opportunities for local people (Canadian Arctic Resources Committee 1994). The Katannilik Territorial Park near Lake Harbour, on south Baffin Island, Northwest Territories, provides an

illustration of how the approach is being implemented (see Box 11.20).

Emerging concepts such as ecotourism, green tourism, and sustainable tourism development are providing the foundation for much more widely acceptable planning, management, and decision-making. It must be recognized, however, that these concepts are general in nature. The specific operational meaning of each term has to be defined and has to evolve in the context of a place or specific situation. Green tourism, ecotourism, and sustainable tourism development are powerful new guiding ideas, but their meaning, planning, and implementation must be built upon careful assessments of the issues in an area, as well as an understanding of the social, economic, and environmental circumstances or context in which they are to apply.

As Hawkes and Williams (1993) have pointed out, the tourism industry itself is now placing much greater emphasis on environmentally sustainable practices: "Sustainable development is, and must be, much more than a politically correct slogan for the tourism industry. Healthy, stable, and diverse physical and cultural environments are the very bedrock of tourism. The industry has recognized this essential fact — and it has begun to act."

A fundamental philosophical shift towards green tourism practices is increasingly reflected in new policies and programs instituted by tourism companies and agencies. In virtually every sector of the industry, environmental initiatives are being explored and implemented.

Tourism associations and some enterprises are discussing ways to monitor the industry's progress. However, key coordinating organizations have yet to commit themselves fully in this direction.

Many studies of sustainable development in tourism have been conducted both in Canada and abroad. Although most of these have focused on economic development and environmental impact, only a few have addressed the actual greening of tourism operations. Still, a number of key Canadian initiatives can be reported, including the 1994 redevelopment of Mont Tremblant, Quebec, and the successful implementation of innovative green practices by companies such as Canadian Pacific Hotels, Delta Hotels, Greyhound Bus Lines, and General Foods Restaurant Properties (Consulting and Audit Canada 1995). Provincially, green routes now exist on the Avalon Peninsula in Newfoundland, and more have been created across the country through rails-to-trails initiatives that convert abandoned rail lines into hiking trails. Green routes and microtourism are showing promise as regenerators for economically depressed regions such as Newfoundland and Cape Breton. Small, green tourism is also emerging as a solution to the problems of areas with multivariate economies, such as the Gaspé Peninsula in Quebec.

Those who participate in ecotourism are beginning a grassroots movement to create the means for ecotourism to fulfil its potential. In large measure, this movement is recognized and promoted by resource managers and operators, as well as conservation organizations and public commentators. Those in the tourism industry who are dependent on a healthy natural environment recognize that they must put their house in order. They believe that should they fail to do so, there is always the prospect that public authorities and agencies will prescribe laws, regulations, and standards to do the job for them. As a first step, the adoption of agreed standards of conduct can be an effective means of linking tourist operators and resource management authorities in implementing environmentally sensitive practices. Experience shows that the most successful standards are self-imposed ones developed by the industry itself and based on well-established ethical codes and operational procedures.

A Code of Ethics and Guidelines for Sustainable Tourism, developed by the Tourism Industry Association of Canada in conjunction with the National Round Table on the Environment and the Economy and the provincial round tables of Prince

Box 11.20
Sustainable development approach to tourism: Katannilik Territorial Park

Katannilik Territorial Park, covering an area of about 1 500 km², was established in 1991, after careful consultation with Native people, to protect a range of landform features, including some in tidal coastal areas. The park is part of the range of the South Baffin Caribou herd and provides habitat for many migratory birds, including Snow Buntings, Horned Larks, sandpipers, plovers, ducks, and waterfowl, seabirds such as the Black Guillemot and Thick-billed Murre, and Gyrfalcons, Peregrine Falcons, Rough-legged Hawks, and Snowy Owls.

The socioeconomic benefits of Katannilik Territorial Park are also important for sustaining the local community. The Interpretation Centre is both a source of employment and a means of reinforcing the local culture. In addition, the park helps to preserve the resource base of the community. Hunting, fishing, and berry-collecting activities are protected, as are traditional land use activities. Before the establishment of the park, there was virtually no tourism in the Lake Harbour area. At the end of the first year's operations, guiding, accommodation, and related services to visitors yielded economic benefits of about $110 000 to Lake Harbour and the region. These benefits have the potential to increase significantly in future.

Some challenges to the role of northern and other parks in sustainable development are apparent in the Katannilik case, including the need to develop the local capacity to manage economic enterprises and the need to clarify the role of parks in natural resource and environmental management.

Source: Downie and Monteith (1994).

Edward Island and Saskatchewan, was adopted in February 1992. The code's objectives are to:

- enhance Canada's image as a destination and its ability to compete in the rapidly expanding world markets for tourism;
- ensure Canada's capacity to provide quality tourism products and services in both the short and long term;
- attract tourists who increasingly are seeking environmentally responsible tourism experiences;
- provide a source of motivation and team spirit for staff at all levels;
- improve the quality of life within host communities; and
- reduce costs through more efficient practices for energy conservation, water conservation, and waste reduction (Tourism Industry Association of Canada and National Round Table on the Environment and the Economy 1992).

Because tourism exists within a broader economic context, there is also a need to debate the sustainability of tourism in relation to the development of other economic activities. Although the debate has been limited to date, a study was recently undertaken in British Columbia to weigh the benefits of tourism development in the Queen Charlotte Islands in relation to fishing, the forest industry, and the protection of Native culture. It concluded that the creation of a national park there could be expected to have a more significant economic impact than logging. In addition, the study showed that positive economic benefits would continue to be derived far beyond the 19-year horizon of projected logging activity. A major advantage of the national park was that it offered a balanced approach to the integration of economic development and natural heritage resource preservation (B.C. Ministry of Forests 1995).

It should also be recognized that tourists themselves are responsible to a large degree for maintaining the natural environments they visit. Public education programs can help to foster appropriate behaviour. It may not be unrealistic to aim for the emergence of an environmental ethic for tourists that implies a moral obligation to behave responsibly towards the environment being visited.

In working towards sustainable tourism development, the following have been identified as important actions to be taken:

- establishing educational and training programs to improve public understanding and to enhance business and professional skills;
- recognizing and understanding the important role of conserving cultural, historic, and biological resources in maintaining and enhancing Canada's base for tourism; and
- supporting the development of tourism impact models to help define appropriate levels and types of tourism and other economic activities for natural and urban areas (Government of Canada 1995b).

In 1994, Statistics Canada developed a new Satellite Account within its System of National Accounts. This new analytical tool has been developed specifically to deal with complex service industries such as tourism. With parallel development work in progress on both a National Tourism Satellite Account and a National Environment Account, a spinoff opportunity exists to link analyses from these two leading-edge development projects and examine the cross-impacts between the two sectors at the national level. Exploratory analyses of this kind might yield new insights into the interdependence of tourism and environmental decisions in Canada.

Internationally, Canada has provided leadership in the development of indicators of sustainable tourism for the World Tourism Organization and has worked with the World Wide Fund for Nature on studies of carrying capacity. Tourism Canada has undertaken initiatives to standardize measures of tourism that facilitate the anticipation of stresses and the measurement of industry response on a consistent basis. Parks Canada has also carried out research into park zoning on an ecological basis, a key tool for tourism management in parks. In addition, some excellent work has been done at the provincial level (e.g., Prince Edward Island and British Columbia) to integrate planning for tourism fully and directly into the overall regional planning process.

Partnerships

Governments, industry, and private citizens all have a role to play in sustaining the outdoor recreation and tourism resources of Canada. Most joint federal, provincial, and territorial activity involving natural resource sectors necessarily affects the resource base and long-term sustainability of outdoor recreation and tourism. In tourism, increasing international competition and an escalating need to promote and adopt sustainable practices are challenges that can be met from the vantage point of a united common purpose.

Canada's comparative advantage lies to a great extent in its environmental resources. Initiatives have been taken with corporate partners to package new soft adventure tours designed to take travellers to new destinations in limited numbers that respect the carrying capacity of these environments. Other initiatives attempt to package travel to spread tourists more widely, thus helping to reduce stress on sensitive or near-capacity destinations. Several joint marketing agreements have been put in place with corporate partners to take advantage of this environmentally focused segment of industry activity (Consulting and Audit Canada 1992).

Management planning is an extremely useful means of establishing the necessary links between governments, industry, and the general public. Moreover, because investment in tourism requires some reasonable long-term security in land use, clarification of development plans and regulations applying to particular areas or resource uses will be of very considerable advantage to tourist developers and operators.

Conclusion

The growth of recreation and tourism has provided Canadians with substantial economic returns, but little is yet known about the environmental costs of recre-

ation and tourism developments. From a qualitative standpoint, these costs may in some cases be unacceptably high, as the evidence of historic recreational land use changes, impacts in national parks, and overdevelopment of shoreline facilities suggests. There is, therefore, a prime need to develop studies of the environmental effects of recreation and tourism. Such studies would address the risks of damaging or destroying the natural resources and environment essential to long-term sustainable recreation and tourism development. In the context of these studies, it is important to try to understand the distribution of the social and economic benefits and associated environmental effects more fully. For example, many of the businesses benefiting economically from outdoor recreation and tourism may do so at rising environmental and social opportunity costs for a wide range of other users.

Given the right framework — government leadership and cooperatively framed regulation, together with enthusiastic commitment and initiative from tourism firms — the world's largest industry can make a substantial contribution to the environment's long-term preservation and development. Much progress has been made in Canada by both governments and industry in awareness program development, codes of ethics and conduct, and environmental impact and other studies. Further progress can be achieved by introducing an environmental dimension into tourist developments and recreational areas at the planning stage and identifying potential impacts so that they can be avoided or mitigated. In this way, the chances of obtaining development sympathetic to the environment will be enhanced.

To be sustainable both environmentally and economically, tourism developments must:

- safeguard the natural environment;
- meet the needs of the host population in terms of improved living standards in both the short and the long term; and
- satisfy the demands of a growing number of tourists and continue to attract them (Cater 1992).

Thus, sustainable tourism relies on development that is appropriate to a locale and sound management practices. These principles are particularly important in the case of rural landscapes, which are increasingly popular as tourism and recreation destinations. Working farms are a good example of how tourism activity in the countryside can be increased, with attendant benefits to the host population and little or no additional impact on the environment (Swinnerton and Hinch 1994).

To ensure that adventure tourism is sustainable, research is required to understand the carrying capacity of the natural resource. This research should measure not only visitor impact on the resource but also the effect of local population pressures, which may overload fragile areas. Adventure tourism activities are both consumptive (hunting and fishing) and non-consumptive (hiking, nature and wildlife viewing, and ecotourism). Caution must be adhered to in local situations where great seasonal influxes of tourists and recreationists can have detrimental effects on wildlife, biodiversity, and landscape quality, both within parks and in adjoining areas.

Given the lack of data and analysis on many tourism impacts, it is difficult at this time to draw firm conclusions about the overall effect of recreation and tourism on environmental sustainability in Canada. However, recreation and tourist activities clearly are a leading cause of localized pressures in areas such as the lower Bow Valley in Banff National Park and have the potential to cause serious damage elsewhere. Furthermore, important tourist resources, including a number of national and provincial/territorial parks, are threatened by environmental stresses originating from other sectors of human activity.

On the positive side, though, progress is being made in developing management tools and strategies to deal with many of these problems. Equally importantly, there is a growing understanding within the recreation and tourism industry itself that its future viability depends on a healthy environment.

Conclusion

Many major economic activities have taken more sustainable approaches in the last five years. In some cases there was no choice: in the Atlantic fisheries, for example, a more conservative precautionary approach to managing the fishery should lead to sustainability, because the only alternative is the disappearance of the resource. In other cases, such as the chemical industry and metal refining, development based on long-term sustainability is proceeding because it makes good economic sense, even in the short term.

Nevertheless, the overall picture that emerges from Chapter 11 shows actions falling short of what is required. If Figure 11.51 were to be extended to cover all the economic sectors reviewed in this chapter, many of the bars on the graph would extend no further than "talking" and "planning"; some would extend as far as "acting," but very few would show Canadians "accomplishing" the task required.

Other important lessons can be drawn from the recent experience reviewed in this chapter. One is that it is probably easier to achieve change where activity and behaviour are structured primarily in large units, such as major corporations. It is harder to make progress when change depends on altering activity patterns in thousands of small firms or millions of individuals and families. If corporate policies in, for example, metal refining, heavy chemicals, or the pulp and paper industry can be redirected towards sustainability, the effect of the policy shift is likely to be swift, substantial, and widespread. Large corporations, in addition to their economic reach, also normally possess the human and other resources needed to implement change adequately and quickly. From this standpoint, for example, the fact that 8% of Canada's farms account for 43% of all farmland is clearly an environmental advantage, even though, from a social perspective, such agribusinesses are seen by many as threatening the survival of the family farm. By contrast, although corporate policy in the automobile and petroleum industries has improved vehicle fuel efficiency and reduced emissions, the need

to provide the opportunity to reduce automobile use by developing more compact cities and the need to persuade millions of individual automobile users to drive less hinder the achievement of a more sustainable transportation sector.

This transportation example suggests another conclusion to be drawn from this chapter: environmental objectives and benefits may be more difficult to establish than is often assumed, especially when the scale involved is that of the whole ecosystem rather than individual species. At the industry scale, the goal of a cleaner, more fuel-efficient vehicle has received much attention, and progress has been made. At the ecosystem scale, however, the goal of reducing carbon dioxide emissions has not been achieved, because more automobiles are on the road.

Environmental objectives may also clash with social objectives as frequently as with economic objectives. For example, it may appear that if clear-cutting of forest areas is unavoidable, the size of the blocks should be as small as possible. But Box 11.4 in the "Forestry" component states that the size of the unit is probably less important than its ecosystem context. Changing provincial regulations on block size may be relatively easy; adapting the regulatory system so that block sizes reflect ecosystem characteristics may be very difficult.

One conclusion that emerges from this chapter is that, in terms of overall effect, cooperative problem-solving and voluntary actions may be more important than government-imposed requirements, and approaches based solely on the use of economic instruments have been less effective. Even if this conclusion is valid, however, it is also clear that there are important qualifications that need to be made and interactions that need to be recognized. For example, much of the emission reduction achieved by metal refiners and chemical producers is a result of voluntary programs adopted within these industries. However, it is clear that market forces (in the form of public opinion) and the threat of future government regulation have been powerful incentives for such voluntary action.

Another lesson is that the lack of reliable and relevant data may have important, even devastating, consequences. The allowable catch established for cod and other species before their collapse depended on biological models of production and on reports of how many fish were caught. Both the models and the reports proved to be imperfect, so that total catches were underestimated and fish production was overestimated. Monitoring resource and environmental characteristics remains both vital and expensive. Selecting reliable measures of environmental health demands much more than a continuation of existing systems, merely because a long time series has been accumulated.

Some lessons from the chapter have obvious implications for public policy. In some provinces, for example, there is a mandatory deposit system for beverages sold in glass bottles, but this does not apply to beverages in aluminum cans. If, as this chapter suggests, the energy required to produce a can from recycled material is only 5% of that needed to produce the same can from aluminum ore, a case may be made for a mandatory deposit system for aluminum cans.

Whether the bottle or can represented by Chapter 11 should be viewed as half full or half empty is not easy to determine. Certainly, the evidence in the chapter confirms the 1994 view of the National Round Table on the Environment and the Economy that there are many clear signs of progress. Governments, corporations, and individuals throughout Canada continue to give high priority to environmental objectives. It is important to remember that phrases such as "ecosystem approach" and "sustainable development" are relatively new to governments, industries, and the general public. They also require an understanding of linkages and interrelationships that were unrecognized, even among scientists, until comparatively recently and that are still being investigated. It is not surprising that it is taking substantial time to adjust values and actions to what these phrases mean. The main concern is that, unless this process can be accelerated, some environmental consequences may be irreversible.

Unfortunately, there is also clear evidence of a widespread reluctance to make major changes in lifestyles and aspirations. People may justify using the car rather than taking the bus on the grounds that the impact of such a change is insignificant unless everyone else does the same. But do they want strong incentives or other action to ensure that this happens? Investing in the future, especially a future expressed in terms of environmental benefits, usually takes a lower priority than spending to acquire goods or enjoyable experiences today. Sustainable lifestyles are as important as sustainable economies, but they may be more difficult to achieve.

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Chapter 12 Urban Canada

Highlights

On balance, are Canadian cities moving towards greater sustainability? In the basic "housekeeping" categories of air and water quality and waste management, progress is being made. This is also true with respect to the conservation of water, energy, and materials, although to a lesser extent; more can be done in these areas. Canadian centres are taking action on the conservation and protection of environmentally sensitive areas, green space, and natural systems. Low-density expansion on the urban fringe is gradually being tightened. New approaches, such as sustainable development policies and state of the environment reporting, are being initiated at the urban level.

■

Further progress by cities in the conservation of energy and land and the improvement of air quality depends on attaining two connected objectives: a more compact urban form and a substantial shift in modes of transportation. These objectives are, in fact, the key to urban sustainability in Canada. Although governments are making substantial efforts towards reaching these objectives, it is by no means certain that enough is being achieved. For example, in many cities, transit service is currently being cut back in light of fiscal restraint. As well, consumer preference for detached single-family homes remains strong.

■

In terms of land area occupied, urbanization in Canada is insignificant: urban areas account for less than 20 000 km^2, or roughly 0.2% of the country's total land area. In terms of population, however, Canada is an urban country: more than three-quarters of its population lives in urban areas. Increasingly, Canadians have congregated in the largest cities: nearly 60% of Canada's urban population lives in centres of 500 000 or more. Whereas the Atlantic provinces are almost evenly divided between urban and rural populations, the central and western provinces are predominantly urban; Canada's "Main Street," extending from Quebec City to Windsor, is the most urbanized region in Canada.

■

The trend towards concentration of Canada's population into the country's largest metropolitan areas has been paralleled by a trend towards deconcentration of the urban centre at a relatively low density into the surrounding countryside. As a consequence of these trends, urbanization in Canada has had a disproportionately high impact on productive agricultural land, prime wildlife habitat, aquatic systems, and other valued components of regional and local ecosystems.

■

The city is an integral component of the broader ecosystem and continuously interacts with it through growth and change in the built environment and human activities and through flows of air, water, energy, raw materials, and waste by-products of many kinds. The total area of productive land, worldwide, required to meet current Canadian demands for resources — Canada's "ecological footprint" — has been calculated to average 4.3 ha per person.

■

Air quality is good in Canadian cities for most of the year. Average levels of most pollutants, as a percentage of the maximum acceptable levels, declined from 1979 to 1993; carbon monoxide, for example, declined by 56%, sulphur dioxide by 46%, airborne particles by 38%, and nitrogen dioxide by 28%. Ground-level ozone is generally regarded as Canada's most serious urban air pollution problem. Attention is also focusing on very small airborne particles, which may be a human health concern. Air toxics such as benzene have recently begun to be monitored in urban areas across Canada.

■

Canadians are profligate users of water. Average household daily use of 335 L per person in 1994 was the second highest in the world. More than 10% of all water withdrawn from natural sources enters municipal systems — half for residential consumption, which increased by almost 23% between 1983 and 1994. Canadian per capita consumption of water is 40% lower in areas where consumers are charged by the volume of water used rather than on a flat-rate basis. The extent and level of municipal wastewater treatment in Canada have been rising steadily but vary greatly across the country.

■

Annual use of energy per person has declined slightly since its 1989 peak of 325 GJ, but it remains high. The transportation sector accounted for 30% of total energy consumption in 1992. On a per capita basis, transportation energy use is less than the Canadian average in dense inner-city areas but higher than the national average in suburban areas.

■

Canadians produce large quantities of municipal solid waste: 1.7 kg daily per person in 1992, of which about one-half was from residential sources. From 1988 to 1992, the discarding of municipal waste declined by nearly 11%, largely owing to impressive increases in recycling and composting by municipalities, households, and businesses. An estimated two million more Canadian households had access to recycling programs in 1994 than in 1991.

■

A 1991 survey shows that total green space, regardless of use or condition, encompassed, on average, nearly 50% of the continuously built-up area of nine large Canadian centres. Despite the use of the ecosystem approach and the increasing acceptance of urban green space as a natural heritage system, parcels of green space tend to remain under constant threat, and city land use controls are not always strong enough to guarantee them permanent protection.

■

Canadians continue to own more cars and drive them further annually. Automobile ownership rose from 140 per 1 000 people in 1950 to 482 per 1 000 in 1992. Despite its important economic and social benefits, widespread automobile use has fundamentally changed the form of Canadian cities, allowing a diffuse, low-density pattern to spread around the older, compact urban area. In this way, the environmental effects of the car, from energy use to air pollution and even climate change, have multiplied.

■

Ever since the industrial revolution, the city has often been depicted as a blight on the "fair face of Nature," an ecological parasite or predator. But this perception is oversimplified. In fact, a strong case can be made that cities are better for environmental protection and resource conservation than dispersed patterns of settlement. Potentially, at least, the city permits economies and efficiencies in the provision of water, sewage, and waste disposal; in energy use; and in the use of land. The city also provides opportunities to substitute walking, bicycling, and transit for car use. It is useful to ask whether human activities are more or less sustainable in cities than anywhere else and whether and how cities can be made more sustainable.

■

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Introduction

Cities exist and function within the hierarchy of regional, continental, and global ecosystems. Invariably, the city's origin and history have been shaped by its natural setting: by climate, by coastlines, by rivers, by the form of the land, and by the qualities of the soil. Increasingly, however, it is now the ecosystem that is affected by the city, in many different ways and from the local to the global scale.

Local landforms and ecosystems are obliterated or irreversibly changed both by the physical fabric of the city and by many urban activities, and these effects spread as the city grows outward. The sheer concentration of people, buildings, and vehicles affects the city's climate and air quality. The city draws on resources from the entire global ecosystem — air, water, land, energy, and a great variety of raw materials — to support its people and to create a vast range of goods and services (Fig. 12.1).

The process of resource transformation and the various forms of transportation needed to serve it produce unwanted by-products in solid, liquid, and gaseous form. Eventually, the useful material products have served their purpose and themselves become scrap or garbage, to join the "waste stream" unless reused or recycled. Human wastes from the millions of city dwellers and other wastes created by their diverse activities add to the volume and variety of unwanted material the city produces. All these wastes in one way or another flow back into the ecosystem of which the city is a part, via air, water, and soil.

Yet city people are largely insulated from that very ecosystem, their ultimate dependence on it obscured by the contemporary urban way of life. Water comes from the tap; meat, fish, and vegetables come, plastic-wrapped, from the supermarket; and waste materials go down the drain or into the garbage truck.

Ever since the industrial revolution, the city has frequently been depicted as a blight on the "fair face of Nature," an ecological parasite or predator. But this perception, still common, is oversimplified. The Canadian city reflects the organization and activities of modern Western society, and it satisfies many human needs. The quality of life that Canadians take for granted can be attained only in an urban society (see Chapter 2). Even those who live in a rural or small-town environment remain part of that urban society and reap its benefits. Thus, to condemn the city is merely to make it the readily identifiable scapegoat for the ecological failings of that society and the economy that it embodies.

In fact, this chapter shows that in relation to the three goals of the World Conservation Strategy (IUCN et al. 1980, 1991) — the conservation of life support systems, the conservation of biodiversity, and the sustainable use of renewable resources — the city, as a highly concentrated form of human settlement, has positive as well as negative aspects. Indeed, Richard Gilbert of the Canadian Urban Institute argues that "Our cities must be seen as the solutions to our environmental and related social problems rather than [as] the problems" (Gilbert 1992).

In the past century, Canadian cities not only have multiplied in size but have changed greatly in their makeup. (In a Canadian context, the word "cities" generally refers to the 25 census metropolitan areas that have "urbanized cores" with populations of 100 000 or more. It may, however, also apply to smaller centres with populations between 10 000 and 100 000. In this chapter, the context makes clear whether the narrow or the broader meaning is intended.)

A hundred years ago, the typical Canadian city was compactly built around a well-defined "downtown" area that was the dominant focus of business and jobs. People moved around mainly on foot or by

Figure 12.1
The city as part of the ecosystem

Source: State of the Environment Directorate, Environment Canada.

public transportation that used the main streets. Goods were carried by horse-drawn vehicles. Wastes were dumped outside the city or burned; sewage was sometimes discharged directly into the lake or river that provided the city with its drinking water.

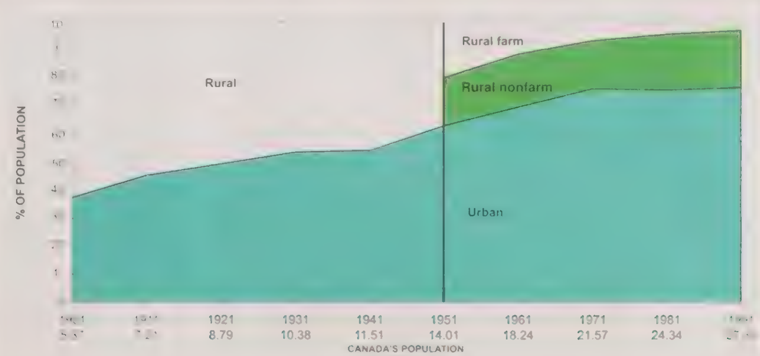
Today, the same city not only is vastly larger (Toronto's population, for example, has increased more than 10-fold over the last 100 years) but is more spread out. People and goods move around mainly by gasoline or diesel power, and green open spaces have been used for expressways, but horse droppings and smoking factory chimneys have largely disappeared. Wastes are discharged in far greater volumes than a century ago; however, they are disposed of with greater care — sewage, for example, is likely to receive some level of treatment before it is discharged. Although cities today are much less dependent on the natural conditions — harbour, lake or river, soil and climate qualities — that gave them birth, their dependence on resource "hinterlands" — not just in Canada but throughout the world — for food, water, energy, and raw materials is many times greater than it was 100 years ago. Thus, the changes that have taken place in Canadian cities over the past century have had both positive and negative impacts on Canada's environment and its resources.

This chapter identifies recent changes in Canada's urban environment and examines how much practical progress is being made towards the goal of urban sustainability. To provide a unified perspective and to emphasize the connections among the various components of the environment and among environmental stresses, an "ecosystem approach" is employed: that is, the city is treated as a dynamic, largely human-made set of systems that is part of a hierarchy of local, regional, continental, and global ecosystems with which it is in constant interaction.

To set its subject in context, the chapter begins by outlining the evolution of urbanization in Canada and the processes of change in urban form and structure that Canadian cities are experiencing.

The chapter then examines in more detail the present state of the various aspects of the Canadian urban environment, the trends affecting it, and the implications for the health both of humans and of the ecosystems of which they are part. The environmental consequences of the automobile are given special attention.

Figure 12.2
Urban and rural population, 1901–1991



Note: For the years 1901, 1911, 1921, 1931, and 1941, the rural population includes both rural farm and rural nonfarm. As the dotted line indicates, rural farm and rural nonfarm populations were first counted in 1951. The rural nonfarm population did not suddenly grow from 1941 to 1951

Source: Statistics Canada (1982a, 1983a, 1993b)

The chapter concludes with a review of what Canadian cities are doing in pursuit of sustainability. It considers whether, in terms of the environmental sustainability of our society, the role of the city is on balance positive or negative and whether Canadian cities are in fact moving towards the goal of sustainability.

Urban Canada

Urbanization and ecosystems in Canada

In terms of land area occupied, urbanization in Canada is insignificant: built-up urban areas account for less than 20 000 km^2, or roughly 0.2% of the country's total land area of 9.2 million square kilometres. However, these figures do not reflect either the great variations in what the land can produce or support or the land use implications of urbanization at the regional and local levels. As discussed below, the direct and indirect ecological impacts of urbanization are much greater than the gross area figures suggest.

In terms of population, Canada is an urban country. During this century, its urban population (living in settlements of at least 1 000 people at a density of at least 400 persons per square kilometre) has grown from under 2 million, about a third of the total population, to nearly 21 million, more than three-quarters of all Canadians (Fig. 12.2).

Not only have Canadians collectively become more urban, they have increasingly congregated in large cities. In 1961, less than 37% of the urban population lived in cities with populations of 500 000 or more. By 1991, this proportion had grown to over 56% of the urban population (Fig. 12.3). Together, the "Big Three" census metropolitan areas — Toronto, Montreal, and Vancouver — housed nearly a third of all Canadians: 14%, 11.5%, and 6%, respectively. Correspondingly, the cities grew more rapidly than the population as a whole: while the country's total population grew by 50% between 1961 and 1991, its urban population increased by 65%, and the population of the very large cities grew by 150%.

Geographically, urbanization is unevenly distributed, even in the relatively densely settled parts of the country. Canada's "Main Street," extending from Quebec City to Windsor, is the most urbanized region of Canada (Yeates 1975). The populations of the central and western provinces are now predominantly urban (over 80% urban in Ontario and British Columbia), whereas the Atlantic provinces are almost evenly divided between urban and rural populations (Fig. 12.4).

The trend towards concentration of Canada's population in the country's urban-centred regions has been paralleled by a trend towards deconcentration of the urban centre into the surrounding countryside. In other words, as a growing proportion of the population has clustered in Canada's large metropolitan areas, these metropolitan areas have spread out at relatively low densities over large areas of formerly rural land, assuming a dispersed form quite different from the compact cities of a century ago. As a result of these two trends, urbanization has had a disproportionately high impact on productive land, aquatic systems, woodlands, and other valued components of regional and local ecosystems.

Furthermore, the ecological effects of Canadians' demands on resources extend through the entire global ecosystem. The total area of productive land, worldwide, needed to meet current Canadian demands — Canada's "ecological footprint" (Rees 1992) — has been calculated to average 4.3 ha per person (Wackernagel and Rees 1996). This land area represents the carrying capacity "appropriated" by each Canadian, using existing technology and maintaining current consumption levels, from the total flow of goods and services provided by the global ecosystem.

A conservative estimate of the ecological footprint for the 1.8 million residents of the densely populated lower Fraser Valley of British Columbia (extending from Vancouver to Hope) is a land area 19 times larger than the actual size of the region (4 000 km^2). The resource consumption and waste assimilation requirements that both the urban and agricultural settlements of this region place on near and distant ecosystems roughly amount to 23 000 km^2 for food, 11 000 km^2 for forest products, and 42 000 km^2 for fossil fuel energy (Rees and Wackernagel 1994; Wackernagel and Rees 1996). (For a discussion of the ecological footprint at the global, community, and household levels, see Chapter 1.)

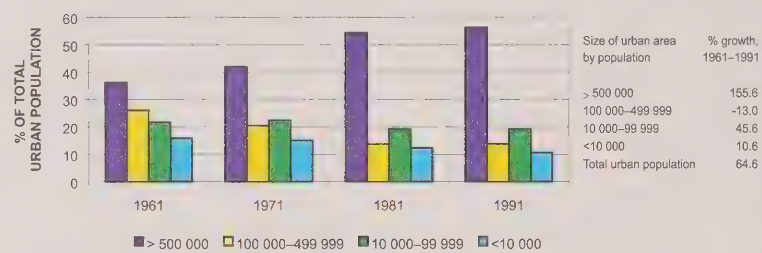
Urban structure and change

The city is much more than the "built environment." The concentration of many people in a relatively small area facilitates social interaction, the production and exchange of goods and services, and access to diverse opportunities for economic advancement, education, and enjoyment.

The city itself is therefore a system made up of at least four distinct but closely related components (Danielse 1991). The physical city comprises the buildings, streets, sewers and water mains, and other relatively fixed, human-made elements. These serve a concentration of people and their diverse activities, which is the second dimension of the city. The third is the almost infinitely complex set of social and economic interactions expressed in many forms of communication and transportation. Finally, there is the dimension of gov-

Figure 12.3

Distribution of urban population by size of urban area, 1961–1991

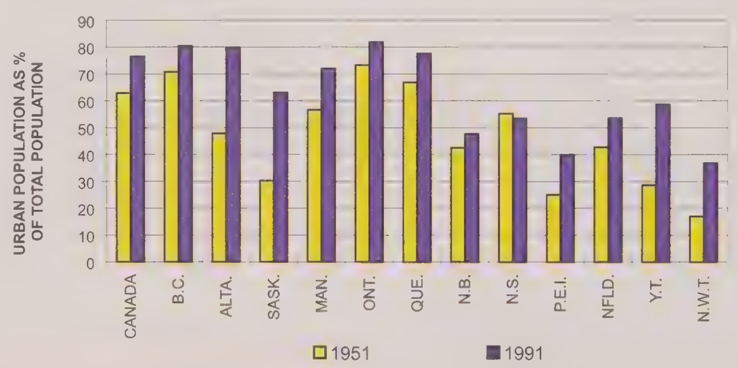


Note: Cities change categories as they continue to expand.

Source: Dominion Bureau of Statistics (1963c); Statistics Canada (1973b, 1982a, 1992b).

Figure 12.4

Urban population by province and territory, 1951 and 1991



Source: Dominion Bureau of Statistics (1956); Statistics Canada (1993b).

ernance: the city as a medium for the management and regulation of human affairs.

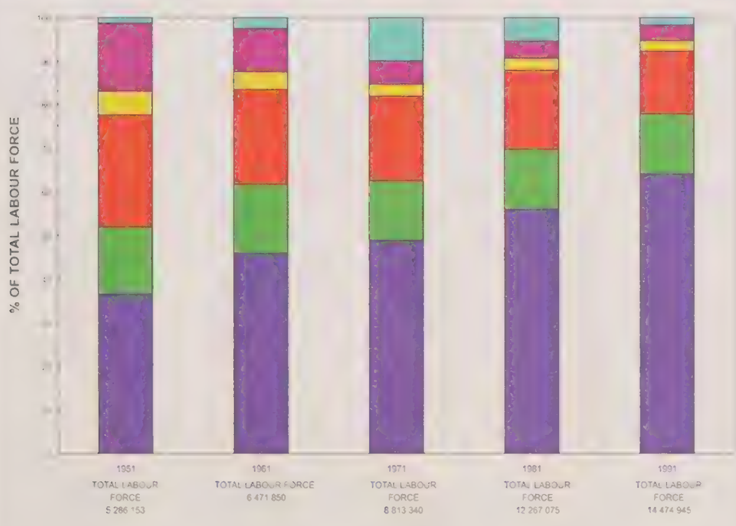
The physical city, the activities of its population, and the means of transportation are intimately interrelated and continuously evolving. Collectively, they have important environmental consequences, both directly and by determining the changing form of the city — its physical pattern and density. These consequences are addressed through the system of regulation and urban management. All four dimensions of the city are considered in this chapter.

Although the urban system stands out as a distinct, internally complex element of the broader ecosystem, the two systems are in a state of continuous, complex interaction through climatic influences, through growth and change in the built environment, and through the flows of air, water, and materials or substances of many kinds. The internal dynamics of the urban system are constantly being altered by other external influences, such as international trade agreements, immigration, and technological advances — to name only a few. Currently, the most important of these influences include economic, demographic, and technological changes.

Economic change

Many cities once thrived on an economic base of so-called "heavy industry": such activities as steelmaking, shipbuilding, and the manufacture of heavy machinery and automobiles. Others depended on industries tied to natural resources: logging and pulp and paper; mining, milling, and smelting; and grain handling. Although these industries still play important roles in the Canadian economy, their proportion of total employment has fallen; at the same time, newer "high-tech" industries have burgeoned, more dependent on specialized training than on ore bodies, deep water, or railways. Whereas employment in the manufacturing sector increased between 1951 and 1991, the "service sector" — covering activities ranging from brain surgery and commercial law to washing windows and serving fast foods — expanded many times faster (Fig. 12.5). These changes in the urban economic base have been accompanied by long-term shifts in the national pattern of goods movement and in the transportation modes used, especially from rail to road and air.

Figure 12.5
Labour force, selected sectors, 1951–1991



Selected labour force sectors	Service	Construction	Manufacturing	Other resource based	Agriculture	Unspecified
% change 1951–1991	380 2	144 6	53 2	22 0	-37 0	not applicable

Notes: Service includes wholesale and retail trade, finance, insurance, and real estate, public and miscellaneous services.
Construction includes transportation, communication, and other utilities.
Other resource based includes forestry, fishing and trapping, mining, quarries, and oil wells.

Source: Dominion Bureau of Statistics (1963b); Statistics Canada (1983b, 1993a).

From an environmental point of view, and also in terms of human health, these changes in the economy are on the whole beneficial, as, relatively speaking, they represent a shift away from types of industry that tend to place heavy demands on natural resources and produce stresses on the environment, such as air and water pollution and large volumes of waste. However, these gains may be more than offset by the shift in transportation from trains to trucks and aircraft, with their high fuel consumption, impacts on air quality, and other adverse effects. The increasing use of electronic communication may in time slow the growth of personal road and air travel, an effect that is already starting to be felt in terms of daily commuting to downtown areas.

Cities are affected by economic change according to their particular circumstances. Many old industrial areas near railways or ports or adjacent to downtown commercial zones have been almost abandoned, in some cases replaced by entirely different uses, while new highway-oriented suburban business centres and industrial districts have emerged. Even the central business districts of some cities have declined as their principal functions diminished in importance or moved elsewhere.

Demographic change

Immigration accounts for half the growth of the Canadian population, and immigrants tend to concentrate in the cities. In 1991, 18.7% of the total urban population had been born in another country, a pro-

portion that had remained relatively stable for a decade. Immigration both stimulates the growth of the urban population and creates culturally diverse cities.

At the same time, the Canadian population is aging (Fig. 12.6), and the average size of a household is shrinking (Fig. 12.7). All of these factors affect demands for housing, transportation, and other services and facilities; for example, the aging of the population may have effects on transit use (Bussière and Dallaire 1994). These changes in demand in turn affect urban form, the extent of urbanization, and resource consumption.

Technological change

More than any other factor, changes in transportation technology are responsible for the form the Canadian city has taken in this century. Now, innovations in information and communication technology are further modifying the urban system by reducing the need for physical proximity to carry out some of the city's traditional functions (Chamberland 1994).

The combined effects of economic, demographic, and technological change, set in the context of each city's particular history and geography, are reflected in its form and pattern of land use.

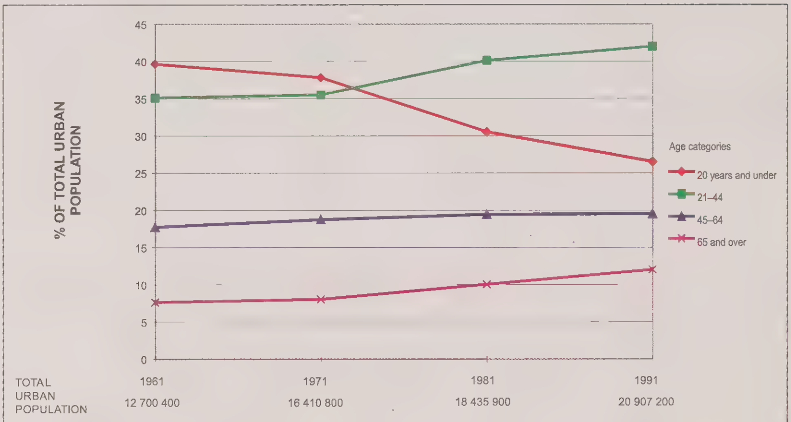
The functions of the central business district have tended to become increasingly specialized as rising rents, congestion, and modern telecommunications combine to encourage many routine activities and operations to move to other parts of the city, or even outside it. The industrial activities that once clustered nearby, on the other hand, have already for the most part either succumbed to economic change or migrated to more spacious and more accessible suburban sites.

However, it is beyond the older, inner area of the city that the greatest changes in urban structure and form have taken place in the 20th century, particularly in its second half. These changes have been made possible by new transportation technology. As the changes themselves, and the technology that permitted them, have had extremely important environmental consequences, they will be looked at in more detail.

Urban transportation and land use

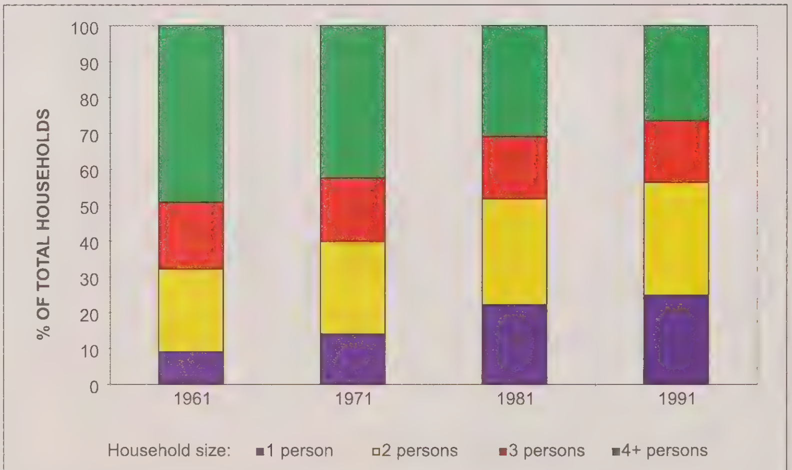
At the beginning of the 20th century, businesses, institutions, and jobs in Canadian cities were concentrated in the central area. Dwellings were closely spaced, and most were within walking distance of shops and transit lines. Travel was mainly on foot or, in the larger cities, by electrically powered streetcars. By mid-century, however, these modes of transportation were being replaced by the private car, and this trend continued rapidly. In communities with public transportation, the number of transit rides per person plummeted from 246 annually in 1950 to just

Figure 12.6
Age of urban population, 1961–1991



Source: Statistics Canada (1982a, 1983a, 1993b).

Figure 12.7
Urban households by size, 1961–1991



Source: Dominion Bureau of Statistics (1963a); Statistics Canada (1973a, 1982b, 1993b).

100 annually by 1970 and have remained fairly stable since that time (Fig. 12.8). Fostered by relatively low prices for both vehicles and energy, heavy public expenditures on expressways and the road system, and socioeconomic factors such as higher household incomes, smaller-sized households, and more women entering the workforce, automobile ownership rose from 140 vehicles per 1 000 people in 1950 to 310 per 1 000 in 1970 and 482 per 1 000 in 1992.

During the 1950–1970 period, a combination of growing prosperity and the "baby boom" was creating an enormous demand for housing. By bringing large areas of relatively cheap rural land within commuting distance, widespread car ownership encouraged this demand to be met by low-density growth on the urban fringe, often termed "urban sprawl." A new urban form emerged, shaped by car-oriented planning. Large lots and areas of open space resulted in population densities half those of the inner city. "Incompatible" activities were segregated by municipal zoning into large tracts of uniform land use (Sewell 1993), so that activities beyond the home generally involved much longer trips than before.

Although car-fed urban expansion has continued ever since, its nature has changed. Commercial, retail, and other service activities are moving to new "town centres" in the suburbs or beyond. Increasingly, the leading edge of urban expansion takes the form not of a continuous extension of the central built-up area, but of rapidly growing clusters physically separate from it (Bryant and Lemire 1993).

As a result, the limits of "the city," as defined in physical and functional terms, are becoming increasingly blurred, while its traditional centralized structure is undergoing great change. The downtown area of the city remains its focus, where key functions are still concentrated, but the suburban "office park," the mall, and the retail "Big Box" now compete with centrally located office buildings and shops. An increasing proportion of residents live in towns, villages, and estate developments some distance from "the city" but remain in touch with the urban core for employment, shopping, and other facilities.

Meanwhile, a new countertrend seems to be emerging. Across Canada, from the immediate post-Second World War period to 1981, inner-city populations declined steadily as a proportion of total metropolitan populations; in the early 1980s, however, this trend reversed. An aging population and smaller households fed a "back to the city" movement to occupy new apartments and renovated older buildings (Statistics Canada 1986).

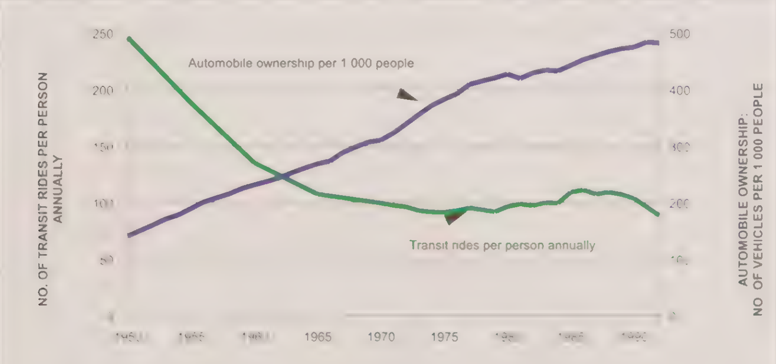
Nevertheless, with the rapid growth of the capability and use of information technology, the decentralizing, dispersing trend will probably continue, despite some limits set by the continuing need for frequent direct contacts for a variety of purposes. "Telework" or "telecommuting" is already growing (Chamberland 1994). It is estimated that between 600 000 and two million Canadians do some or all of their paid labour at home (CMHC 1995; Gurstein et al. 1995).

The urban region — the entire area economically and demographically dominated by a core city or group of cities — seems likely to replace "the city" as a meaningful geographical entity, as is happening, for example, in the Greater Toronto Area or, more broadly, in south-central Ontario. More and more Canadians are living and working within urban regions, yet the average population density of these spread-out cities is declining.

This new urban structure has undesirable aspects. For example, competition among municipalities can result in a proliferation of malls and office and industrial parks and in expansion of services before the existing infrastructure is effectively utilized. But it also has considerable positive potential. It can provide opportunities to reduce daily travel by bringing employment, services, and residential areas closer together, as, for example, Greater Vancouver's Liveable Region Strategy seeks to achieve (GVRD 1993a). It can make recreation areas and the countryside more accessible to urban residents. The key is effective, far-sighted planning on a regional scale, rather than allowing the new pattern to "just happen."

However, the sheer physical expansion of the urban area onto rural land and the simultaneous enormous growth of car use raise serious ecological issues concerning land resources, energy use, air quality, and global warming.

Figure 12.8
Automobile ownership per 1 000 people and urban transit rides, 1950–1992



Source: Statistics Canada (various years), Canadian Urban Transit Association (various years), developed by IBI Group

The Canadian system of cities: environmental themes

Although Canadian cities occupy a tiny proportion of the country's total land area, they tend to be clustered in the most productive ecozones. These ecosystems therefore bear the brunt of urban impacts on air, water, and land.

As already mentioned, every city comprises complex systems that are continuously evolving in response to three principal influences: changes in the economy, changes in the size and composition of the population, and changes in technology, particularly in the realms of transportation and communication. A massive shift from public transportation to the private car has enabled cities to spread far beyond their old core areas and, in conjunction with electronic communications, is creating a pattern of decentralized nodes of activity within large urban regions.

When these conditions are related to the three goals of the World Conservation Strategy (IUCN et al. 1980, 1991) and to considerations of human health, four themes can be identified:

- the demands of urban populations for renewable and nonrenewable resources, including water, energy, land, and materials from near and distant ecosystems;
- the stresses on regional and global ecosystems and on human health from pollutants and wastes originating in urban populations and activities, including transportation;
- the direct and indirect impacts of urbanization, particularly of a car-oriented urban form, on the air and on terrestrial and aquatic environments; and
- the overall balance sheet, in terms of ecological sustainability, for the evolving pattern of large, low-density cities in Canada.

These basic themes are explored with varying levels of emphasis in the remainder of the chapter.

URBAN ENVIRONMENTAL CONDITIONS AND STRESSES

The following review focuses on *urban* environmental conditions and trends; other chapters deal with individual aspects of the environment in more detail. Although this review is presented under a number of separate headings — air, water, energy, materials, land — all of the conditions are to a greater or lesser extent interrelated, particularly in their cumulative impacts on regional and global ecosystems. The question of how urban Canadians are responding to the outlined conditions and working towards improved environmental sustainability is dealt with later in the chapter.

Air and climate

Human beings have been adding pollutants to the air since our ancestors learned to use fire. The polluting continues, but now we know that the quality of the air we breathe may be affected by activities hundreds or even thousands of kilometres distant. Until quite recently, climate at least was thought to be immune from human influence, although the prospect of global warming has taught us that this is probably not so. In fact, a city — its structure and form and the activities that take place within it — can modify the climate in its own vicinity, its "microclimate."

Microclimate

Five main factors shape a city's microclimate, relative to the surrounding rural area: storage and reradiation of heat by streets and buildings; reduction of wind speed, which diminishes the wind's cooling effect in summer; human-made sources of heat; rapid runoff of precipitation, which reduces the cooling effect of evaporation; and the effects of atmospheric pollutants (Hough 1984).

The net result is the "urban heat island" effect: average temperatures in the city are 1–2°C higher than in the surrounding area, and temperatures in extreme cases can be as much as 12°C higher. For example, the mean annual temperature at Edmonton's Municipal Airport, inside the city limits, is 1.5°C higher than at the International Airport, 20 km to the south (Phillips 1990). This effect has implications for energy consumption (cities need less for heating but more for cooling) and for the use of chlorofluorocarbons (CFCs) or CFC substitutes for cooling.

Box 12.1
Air pollutants in Greater Vancouver

In 1990, in Greater Vancouver we pumped more than 600,000 tonnes of pollutants into the air (enough to fill B.C. Place Stadium 390 times). This pollution included 385,000 tonnes of carbon monoxide (CO), 85,000 tonnes of volatile organic compounds (VOCs are gases such as various solvent and fuel vapours), 53,000 tonnes of nitrogen oxides (NOx), almost 8,000 tonnes of sulphur oxides (SOx), 19,000 tonnes of particulate matter (soot, flyash and dust), as well as a host of hazardous air pollutants such as benzene and lead. Most of this pollution was produced by motor vehicles.

When the wind can't disperse these pollutants, the result is a brown haze that can stretch from Vancouver to Abbotsford and beyond — a distance of more than 50 km. This photochemical smog is a "soup" of different air pollutants that can have serious effects on human health, wildlife, livestock and vegetation.

Components of this smog can damage the lungs of the young and the old. For those people with asthma, smog can worsen an attack. It can raise the risk of getting respiratory diseases, such as bronchitis, and raise the risk of developing certain types of cancer. This smog also damages crops, natural vegetation and even buildings.

Source: Excerpt from GVRD (1994).

Air quality

Although activities and events that cause air pollution are by no means confined to cities (pulp mills, refineries, and forest fires are examples of sources outside cities), it is in cities that many different sources are concentrated. Thus, national air quality data and trends usually reflect urban conditions (Box 12.1).

This does not mean that air pollution in every Canadian city is entirely of the city's own making. The quality of the air in some cities, especially in the Windsor–Quebec City corridor and in parts of the Maritimes, is affected by the long-range transport of pollutants from other areas, predominantly in the United States.

Atmospheric levels of sulphur dioxide, suspended particles, ground-level ozone, carbon monoxide, and nitrogen dioxide in cities are measured by the National Air Pollution Surveillance (NAPS) network. (The human and environmental effects of these pollutants are described in Chapter 10.) The NAPS data for the five common pollutants are compared with a consistent benchmark, the National Ambient Air Quality Objectives (NAAQOs), which are set out in the *Canadian Environmental Protection Act*. The NAAQOs define three levels for each pollutant: *maximum desirable*, the long-term goal; *maximum acceptable*, which provides adequate protection of human comfort and well-being and of soils, water, and vegetation; and *maximum tolerable*, the level beyond which action is needed to protect human health.

The NAAQOs do not include standards for the "greenhouse gases," such as carbon dioxide, which contribute to global warming (see Chapter 15). Urban traffic, in large part generated by the spread-out urban form, is a major source of carbon dioxide. Cities also generate carbon dioxide, as well as other greenhouse gases, in other ways, such as through the heating of buildings, industrial processes, and waste disposal. A study in the City of Ottawa revealed that energy use caused the emission of 3 902 kt of carbon dioxide in 1990, 21% of which came from natural gas, 31% from electricity, and 48% from oil products (Millyard 1992). By sector, residential energy use accounted for 23% of emissions, commercial 31%, industrial 10%, and transportation 36% (Millyard 1992).

Average levels of most of the pollutants measured by the NAPS network, calculated as a percentage of the respective maximum acceptable levels, declined from 1979 to 1993; for example, carbon monoxide declined by 56%, sulphur dioxide by 46%, and airborne particles by 38%. Average nitrogen dioxide levels in cities fell by 28% between 1979 and 1993, despite an estimated increase of 13% in distance travelled by passenger vehicles (Environment Canada 1996a; River Road Environmental Technology Centre, unpublished data). The only exception was the rise in average ground-level ozone concentrations by 29% over the same period.

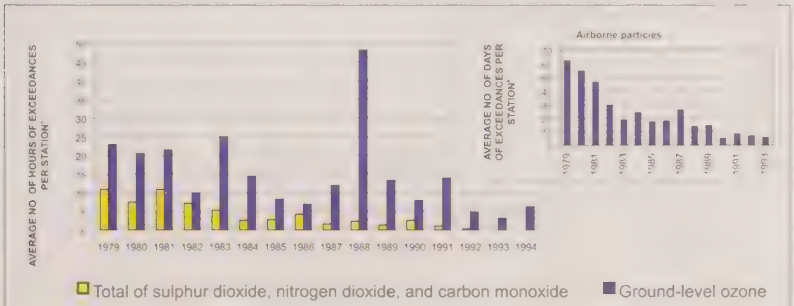
Also, the number of hours of high readings or exceedances (episodes when pollution exceeds the maximum acceptable level) has declined for most major pollutants, particularly sulphur dioxide, carbon monoxide, airborne particles, and, to a lesser extent, nitrogen dioxide. The reasons for the declines include the introduction of catalytic converters in cars, cleaner-burning engines, cleaner gasoline, more and better scrubbers on industrial smokestacks, and greater overall energy efficiency (Environment Canada 1996a).

In general, the air quality is good in Canadian cities for most of the year. Over the 1979–1993 period, air quality particularly improved in the larger Canadian cities, where vehicles are a significant source of air pollution. In 1988, the worst year for episodes of ground-level ozone in southern Ontario, the 48.2 hours of exceedances of the maximum acceptable level for ozone experienced on average in urban Canada represented less than 1% of the total number of hours in a year (Fig. 12.9).

Although their overall level has declined steadily, airborne particles (dust, smoke, pollen, and other minute solid particles) are a cause for concern in Canadian cities. The level of particles remains relatively high, and cities continue to experience periodic exceedances (Fig. 12.9, inset). Although the levels of all particles measuring less than 100 μm in diameter (the width of the average human hair) are declining significantly owing to better control of industrial and vehicle emissions and less open burning, concern is now focusing on small particles measuring less than 10 μm, referred to as PM-10. These small par-

Figure 12.9

Number of times air quality objectives exceeded, urban Canada, annually since 1979



Note: The combined level of exceedances for the SO_2, NO_2, and CO are presented for 1979–1992. Exceedances for airborne particles are provided for 1979–1993, and measurements of ground-level ozone for 1979–1994.
N/A = data not available

[a] Refers to the average number of hours of exceedances of the maximum acceptable levels at class 1 stations in urban areas across Canada. Measurements are generally taken hourly throughout the year. Ozone measurements are generally taken hourly April through September. Ozone levels have been normalized to 100% of readings per station to compensate for missing readings for each month during this period each year. Maximum acceptable levels are 82 ppb for ozone (1 h), 344 ppb for SO_2 (1 h), 213 ppb for NO_2 (1 h) and 13 ppm for CO (8 h).

[b] Measured at class 1 stations over a 24-hour period once every six days and multiplied by six. Maximum acceptable level is 120 μg/m³ (24 h).

Source: Graph based on data provided by River Road Environmental Technology Centre, Environment Canada, Ottawa. See also Environment Canada (1996a).

ticles account for approximately one-half of the weight of total particles measured. In Canada, separate monitoring of smaller particles has recently begun in both the Toronto and Vancouver areas. An NAAQO for PM-10 is under development, and an indicator based on a PM-10 objective may be available by 1997.

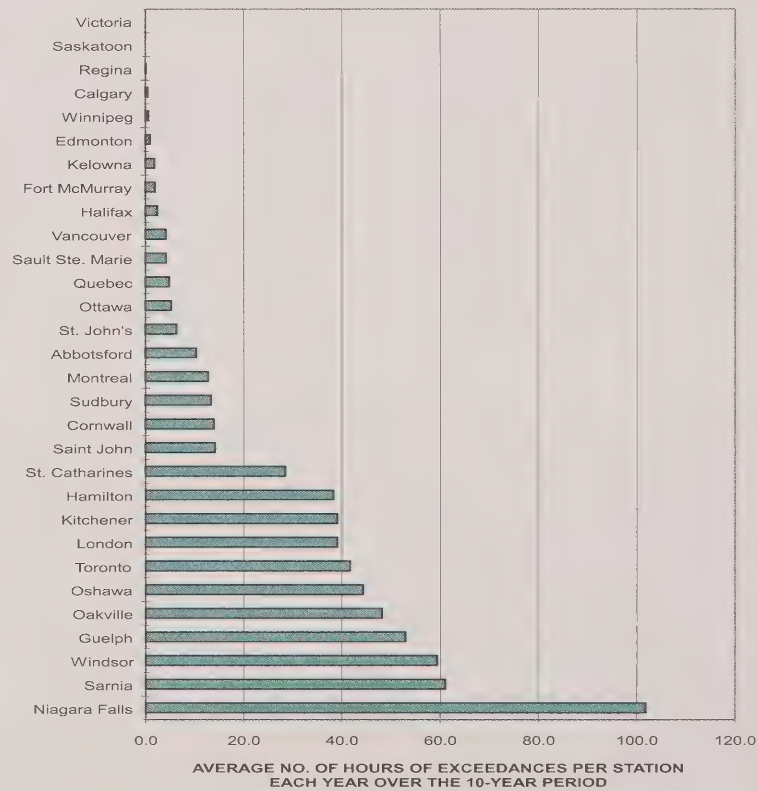
Recent research suggests that very small airborne particles of 2.5 µm or less may be a special cause of concern for human health. These particles, which can enter the lungs after inhalation, are believed to contain unburned pieces of carbon originating from the combustion of fossil fuels in vehicles and the heating of buildings. These minute particles, which are difficult to see even with a high-powered microscope, may thus carry quantities of other pollutants, which can adhere to the carbon (Environment Canada 1996a).

Regional patterns of urban airborne particle levels are similar to the national average, except that Alberta cities have historically been dustier than the average, and Maritimes centres less so.

Ground-level ozone may be a more important aspect of urban air pollution than particles. It is formed by a reaction between nitrogen oxides and volatile organic compounds (VOCs) (known as its "precursors") in sunlight. Although in 1992 the hourly average values in Canadian cities were substantially lower than in several large U.S. cities (Environment Canada 1994b), ground-level ozone is generally regarded as Canada's most serious urban air pollution problem. The hourly average value has generally remained well below the maximum acceptable level of 82 parts per billion (ppb) since the mid-1980s, but periodic exceedances continue. There are no clear trends in the levels of ozone, as weather strongly affects its formation. Episodes of high ozone levels were particularly frequent in 1988, a year of unusually hot and stagnant weather in central and eastern Canada (Fig. 12.9). In that year, Montreal recorded 60.8 hours of exceedances, Toronto 127.2, and Vancouver 14.9. This means that, in 1988, each city experienced a number of summer afternoons during which the air quality fell below the level needed for the full comfort of humans and adequate protection of water, soils, and vegetation. By comparison, many U.S. cities have several times the number of annual ozone exceedances of their Canadian counterparts (Environment Canada 1996a).

The seriousness of the ozone problem varies from city to city and from region to region, depending not only on the form and other characteristics of the city itself (topography, industrial base, land use, commuting patterns, etc.) but also on its location relative to external sources of ozone and prevailing winds. Average ozone levels in Canada's settled rural areas downwind from large cities are generally higher over the course of a year than in urban areas. The Canadian Council of Ministers of the Environment (CCME 1990) has identified three ozone problem areas: the lower Fraser Valley, which is affected by

Figure 12.10
Ground-level ozone: the number of hours its air quality objective was exceeded annually in selected Canadian cities, 1985–1994



Note: Refers to the average number of hours of exceedances of the maximum acceptable level at stations within each urban area. Values in centres with more than one station have been averaged for each year first. Stations in rural areas or small towns and with insufficient records over the 10-year period have not been included. Measurements are generally taken hourly April through September. Measurements have been normalized to 100% of readings per station to compensate for missing readings, for each month during this period each year. Maximum acceptable level is 82 ppb (1 h).

Source: Graph based on data provided by River Road Environmental Technology Centre, Environment Canada, Ottawa. See also Environment Canada (1996a).

ozone from the Vancouver area; the Windsor–Quebec City corridor, which is affected both by local sources and by sources in the U.S. Great Lakes and Midwest regions; and the Fundy region of southern New Brunswick and western Nova Scotia, which is affected by sources in the northeastern United States (Environment Canada 1992, 1996a). By contrast, ground-level ozone is not a problem in Prairie cities or in Victoria, which have neither the density of vehicles nor the prevailing winds from industrial areas needed for ozone episodes to develop (Fig. 12.10).

These statistics reflect the average situation: each city has its unique pattern of air pollution. Point sources, such as industrial plants, incinerators, and generating stations, are fixed and are likely to be clustered in particular parts of the city. Non-point or dispersed sources include vehicles and the heating of buildings; these are widely distributed, but their pollution effects tend to be concentrated in densely built-up areas and along traffic arteries. Leaks and unintended releases of pollutants ("fugitive emissions") may occur anywhere but are most likely to affect industrial areas and transportation corridors (City of Toronto Department of Public Health 1993). Therefore, concentrations of different pollutants often vary widely from one part of the city to another and at different levels above the ground.

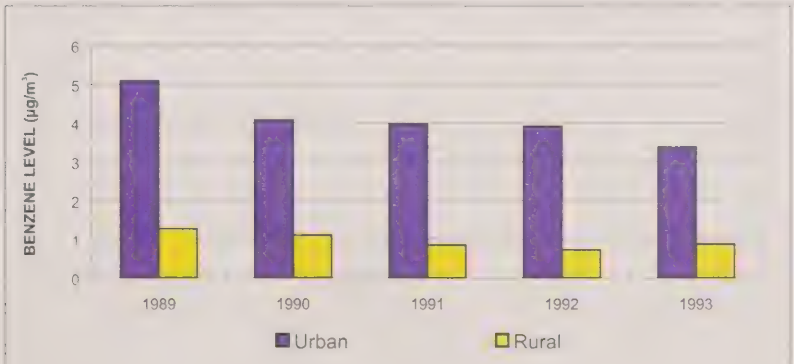
In addition, many air toxics are beginning to be monitored in several large urban areas. Air toxics include VOCs such as benzene, other chemical compounds, and metals such as lead. They come from diverse sources, including industrial processes, vehicles, and incineration. Concentrations are generally low compared with concentrations of the pollutants already mentioned, although their relative toxicity is often greater. Approximately 160 toxic compounds have been detected in Toronto's air. Of these, 4 are known human carcinogens and 27 are suspected human carcinogens (City of Toronto Department of Public Health 1993). A concern to many is the sheer number of air toxics and their contribution to the overall toxicant burden in the human body. The extent of the effects of low concentrations of air toxics on human health is not known, but monitoring of selected toxics such as benzene has commenced across Canada as a precautionary measure.

Benzene is one of the air toxics known to cause cancer in humans. It initiates tumours and has been linked to a specific form of leukemia. Based on its human health effects, benzene is considered to be "toxic" as defined under the *Canadian Environmental Protection Act* (Environment Canada and Health and Welfare Canada 1993). Benzene is a natural component of crude oil; its concentration is increased to an average of 2.1% by volume to boost the octane rating of gasoline. It is also an intermediate in the production of numerous chemicals. The main source of outdoor airborne benzene in Canadian cities is the exhaust and evaporative emissions of motor vehicles. It was estimated as of 1991 that transportation sources accounted for over 85% of the benzene released into the atmosphere in urban areas (Dann 1994). Recent research has found that 20–30% of outdoor airborne benzene, calculated on a national basis, is derived from natural gas dehydrators — a previously unknown source — that are located primarily in Alberta (M. Tushingham, Environment Canada, personal communication).

Canada does not have a health standard for airborne benzene. However, "the highest concentration of benzene in ambient air measured in Canada is almost 240 000 times lower than the lowest concentration reported to be lethal to plants, terrestrial invertebrates and laboratory mammals following acute exposure to benzene in air" (Environment Canada and Health and Welfare Canada 1993). Apart from cigarette smoking, which is by far the principal source of adult exposure to benzene, breathing city air is the most common form of exposure (Environment Canada and Health and Welfare Canada 1993). Very little is known about the human health effects of prolonged exposure to trace amounts of benzene in city air.

In Canada, average benzene levels in urban air are generally about four times higher than those in rural air. During the five years in which benzene has been widely monitored in Canadian cities, average airborne concentrations have fallen by one-third (Fig. 12.11). This is due to better emission controls on vehicles and to more efficient engines. The downward trend should continue. In July 1995, Environment Canada announced that it would

Figure 12.11
Average benzene concentrations in the air, 1989–1993



Note: Data were derived from 24 urban stations and 5 rural stations; however, only 12 stations operated for the full time period each year.

Source: River Road Environmental Technology Centre database, Environment Canada, Ottawa.

limit benzene in gasoline to a maximum of 1% by volume and not permit any increase of other aromatics in gasoline.

In summary, air quality in Canada's urban areas can generally be regarded as good. With the possible exception of ground-level ozone, which is a continuing concern, the average levels and number of exceedances recorded for the main air pollutants in Canadian cities have declined over the past 15 years. Concern over the effects of very small airborne particles and air toxics such as benzene has led to the monitoring of these substances. But a cautionary note is called for: as long as car ownership and use continue to rise and traffic congestion continues to grow (overwhelming the per vehicle reductions in energy use and airborne emissions), it is unlikely that overall levels of air pollution will continue to decline (IBI Group 1995).

Water

Cities in the hydrologic cycle

The relationship of cities to the flows and transformations of ecosystems is clearly seen in the way cities are linked to the hydrologic cycle — the continuous cycling of water from one form to another in the global ecosystem. Typically, a city will withdraw water (perhaps already contaminated) from a lake or river and treat it to make it potable. The water will then receive a variety of pollutants, including human wastes, so that it must be treated again before being returned to the hydrologic system, where it is further cleansed by natural processes. Downstream, other communities that depend on the river for their own supply put their water through a similar sequence of treatment processes (some perhaps discharging their wastewater untreated). Eventually, the river carries the water, with whatever pollutants remain, into the ocean. There, the hydrologic cycle is continued through the natural processes of evaporation, transportation as clouds, and precipitation (Box 12.2).

Water supply and water quality

Most Canadian cities rely on surface sources — lakes or rivers — for their water supply, but slightly over 2 million urban Canadians, nearly 10% of the population served by municipal systems, relied on groundwater (Environment Canada 1996b). Both types of sources are susceptible to problems of availability and quality.

In 1991, one Canadian municipality in five with water supply systems reported problems with availability during the previous four years (Environment Canada 1994a), meaning that residents might be faced with shortages or use restrictions. For cities relying on surface water, such problems are generally seasonal and temporary. However, cities relying on groundwater, notably in Prince Edward Island and southern Ontario, may have to face the possibility of a long-term decline in supply. The depletion of the groundwater supply for Kitchener–Waterloo has led to a quest for alternative sources, including the possibility of a 120-km pipeline from Georgian Bay. Even cities using surface water may have to choose a similar course or raise the treatment level of the water that they currently obtain from a source whose quality is questionable or deteriorating; Regina is one city that has faced this dilemma.

Depending on location and a number of related factors, both surface water and groundwater can be contaminated by many possible sources, among them drainage or seepage from industrial, commercial, residential, and even recreational land uses, including waste disposal sites; runoff or seepage of farm manure, chemical fertilizers, and other agricultural chemicals; spills and discharges from shipping; and deposition of atmospheric pollutants. Consequently, the water must be filtered and treated chemically to restore it to a quality that is safe for human consumption before it is pumped into the city's distribution system.

Recent studies indicate that urban water quality is generally good in Canada, but the quality differs considerably from place to place, as does the extent of monitoring. A study carried out by the City of Toronto

Box 12.2
A pretty average day

At five o'clock in the morning in early July, the rain began, slowly at first and then with increased intensity. It struck roof tops and trickled down gutters, gathered on driveways, parking lots, and roads. Along its way, the swirling stormwater picked up animal feces and herbicides from parks and yards, as well as asbestos, oil, and grease from roads. Before the rainfall ended, 4.5 billion litres of rainwater had gushed into the labyrinth of storm sewers under the metropolis.

At seven o'clock, people began to rise, taking showers, brushing teeth, and flushing toilets in 1.5 million households. By eight o'clock, when most had left for work or school, 770 million litres of wastewater had gone down household drains and into the sanitary sewer system. Combined storm and sanitary sewers were overflowing, and a noxious brew of stormwater and untreated sewage was flowing into local rivers or surging towards the sewage treatment plants. By nine o'clock, the hopelessly overburdened treatment plants began to bypass partially treated effluent directly into the nearshore of Lake Ontario.

. . .

Unseen by commuters, the brown and swollen rivers in the area disgorged their loads of sediments and toxic chemicals into Lake Ontario. At the river mouths, fishermen tossed their catches back into the lake, mindful of the signs that warned against eating fish. "Just a reminder to stay out of the water at area beaches for two days after this rainfall," the radio voices continued. By mid-morning, public health officials would be testing water at the beaches lining the waterfront; in less than a week, many would be closed to swimmers.

Source: Excerpt from Royal Commission on the Future of the Toronto Waterfront (1990).

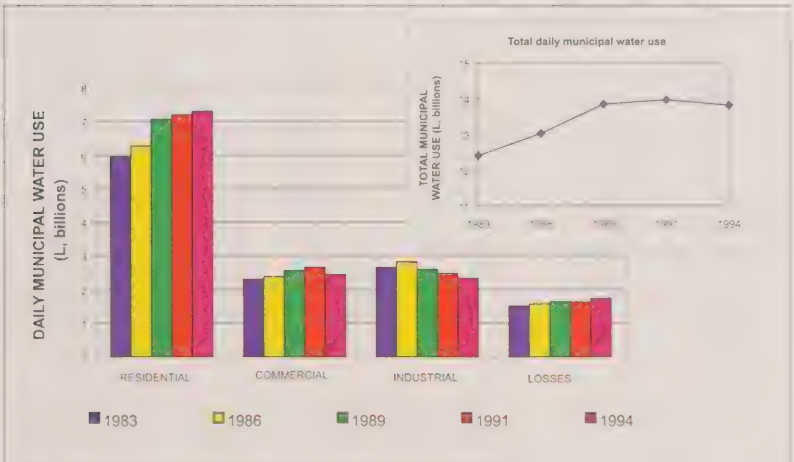
Department of Public Health (1990) concluded that although tap water in that city contains many of the chemicals detected in the water, sediments, and biota of the Great Lakes ecosystem, most chemicals occur at very low levels, well below what would constitute a health concern. Nonetheless, some priority chemicals of concern were identified, including trihalomethanes (a by-product of the chlorination of organic matter in raw water), lead, and aluminum, for which reduction in exposure was recommended.

On the other hand, according to a recent annual report of Ontario's auditor, 120 of the province's 490 water treatment plants, serving nearly a million people mainly in smaller communities, either do not meet provincial guidelines on treated water quality or on treating bacteria or have not performed sufficient testing for bacteria and toxic chemicals to determine if the guidelines have been met (Office of the Provincial Auditor 1994).

A recent report on the Greater Vancouver Regional District's Drinking Water Quality Improvement Plan claims that tap water in the Greater Vancouver Area is currently safe to drink but acknowledges that it no longer meets the new, more stringent Canadian Drinking Water Guidelines set by Health Canada (GVRD 1993b). "Ensuring a sufficient supply of clean drinking water for our children means considering water supply and quality concerns before they become problems," states the study. The report refers to four specific areas of concern, all involving some potential risk to health: inadequate disinfection of water sources; seasonal coliform bacteria regrowth, not harmful in itself but indicating the possibility that harmful bacteria could survive; seasonal turbidity, or cloudiness; and natural acidity or corrosiveness. The proposed improvement plan is likely to involve an expenditure of up to $500 million over a period of several years.

In the Montreal Urban Community, it has been noted that "The drinking water distributed to residents . . . observes the standards set by [provincial] regulation and poses no danger to health as far as the regulated contaminants are concerned. Certainly, contamination may occur due to a technical breakdown or an accidental spill, but . . . preventive and corrective procedures have been designed to achieve a quick return to normal conditions" (translated from Roy et al. 1989).

Figure 12.12
Daily municipal water use by sector, 1983–1994



Note: "Losses" includes unaccounted water use, such as water used for firefighting.

Source: Environment Canada (1996b); data derived from Municipal Water Use database, Water Program, Environment Canada

Water use and wastewater treatment
More than 10% of all water withdrawn from natural sources in Canada enters municipal systems to supply residents, businesses, and some industries. Over half the water in municipal systems supplies residential consumption, which increased by nearly 23% between 1983 and 1994 (Fig. 12.12), despite an increase of less than 16% in municipal population served water. Within the home, most water is used in the bathroom, but residential water use can rise by as much as 50% on peak days in summer owing to lawn and garden watering and car washing. Thus, the extended form of the modern city, with a large portion of the population living outside the urban core, contributes to excessive water use.

Canadians are in fact profligate water users: the average household daily use of 335 L per capita in 1994 was the second highest (after the United States) in the world (Environment Canada 1996b). This can largely be attributed to low prices and flat-rate pricing (as distinct from charging according to the volume of water used). Water use responds closely to price: of several Western industrialized countries, Canada has the lowest average water price, and Canadian per capita consumption is on average 40% lower where consumers are charged by the amount they use rather than on a flat-rate basis (Environment Canada 1994a). For example, per capita consumption of water is 60% higher in Calgary, which charges a flat rate, than in Edmonton, which charges according to volumes used.

The built-up nature of the city creates a unique hydrologic environment. "Asphalt and concrete replace the soil, buildings replace trees, and the catch basin and storm sewer have replaced the streams of the natural watershed. The amount of water runoff is governed by the filtration characteristics of the land and . . . is directly related to the percentage of impervious surfaces" (Hough 1984).

Most of the water in a municipal supply system is used to carry away myriad domestic, industrial, and commercial wastes, including human sewage, becoming far more highly and variously contaminat-

ed than before. These wastes comprise mainly decomposing organic matter (which contributes to eutrophication, or excessive algal growth that depletes the dissolved oxygen needed to sustain aquatic life), suspended solid material, and phosphorus, but there may also be small quantities of other contaminants such as liquid industrial wastes. As most of the wastewater reenters the natural system, it must be treated to remove at least a portion of these impurities. The primary purpose of treatment is to safeguard human health, but large and ever-increasing volumes of wastewater treated to a level adequate for health protection may still place stress on aquatic ecosystems.

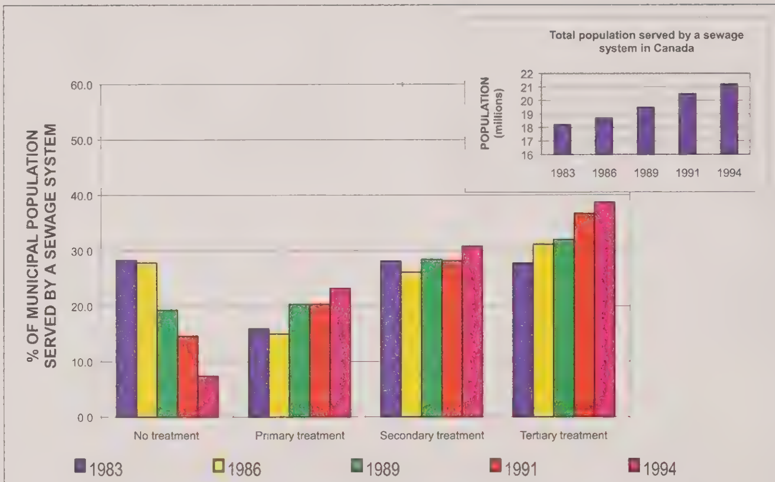
There are three levels of sewage treatment. Primary treatment merely filters out solid matter, secondary treatment removes biological impurities as well, and tertiary treatment removes the nutrient content and chemical impurities remaining after secondary treatment. Tertiary treatment is required to return water to an approximation of pristine condition.

The existence of a treatment plant does not necessarily ensure that all the water returned to the natural system has been treated. Storm drainage, from rainwater and melting snow, may remain entirely untreated, carrying animal feces, oil from gas stations and driveways, garden chemicals, and many other pollutants into the ocean, lake, or river. Some cities, such as Vancouver, do not separate storm and sanitary sewage; even in cities with separated systems, storm drainage flow may overload the plant's capacity in periods of heavy rain or spring runoff, so that both storm drainage and sanitary sewage are discharged untreated.

In general, the level of municipal wastewater treatment in Canada has been rising steadily (Fig. 12.13). In 1983, 18.2 million people, three-quarters of the total population (including all city residents), were served by sewage systems, and 13 million of these (72%) were also served by some form of sewage treatment. The wastewater of the remaining 5.2 million was discharged untreated. By 1994, the number served by sewers had risen to 21.2 million. Of these, 19.6 million (93%) were also served by some form of treatment, while the wastewater of 1.6 million was discharged without treatment. During this period, the numbers served by tertiary treatment rose from 5 million to 8.2 million, 39% of the population served by sewers (Environment Canada 1996b).

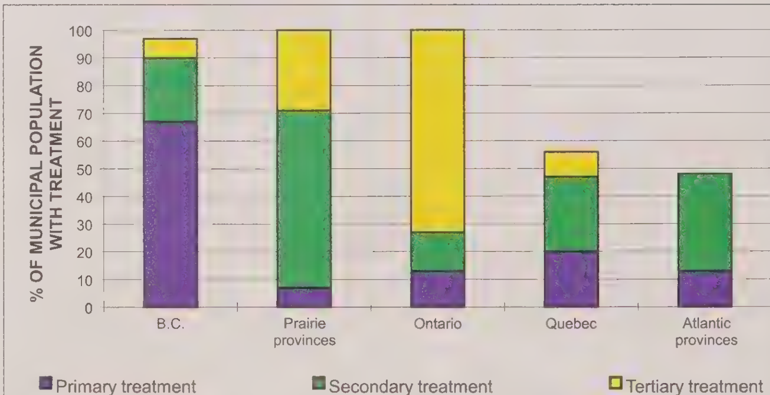
However, the level of wastewater treatment varies greatly across the country, largely reflecting the nature and scale of the receiv-

Figure 12.13
Municipal wastewater treatment, 1983–1994



Source: Environment Canada (1996b); calculations based on data derived from Municipal Water Use database, Water Program, Environment Canada.

Figure 12.14
Municipal wastewater treatment by region, 1994



Note: Insufficient data were available for the territories.

Source: Environment Canada (1996b); calculations based on data derived from Municipal Water Use database, Water Program, Environment Canada.

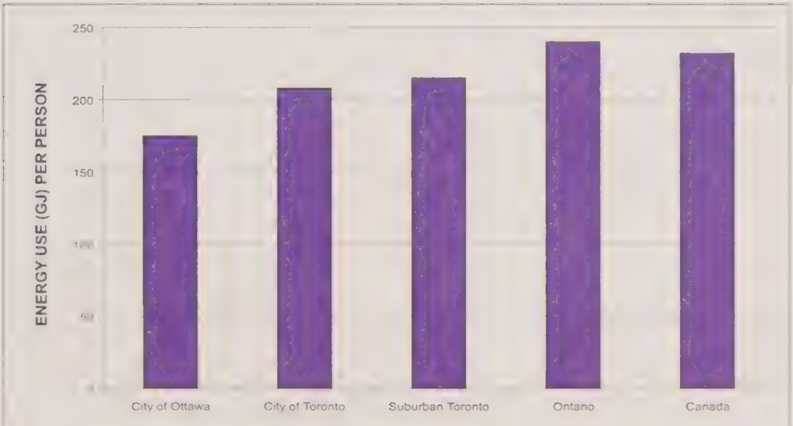
ing waters (Fig. 12.14). Whereas many coastal cities discharge their wastewater directly into the ocean, and cities on the lower St. Lawrence into that river, most Ontario cities must discharge into smaller rivers or the Great Lakes, and Prairie cities discharge exclusively into rivers. Thus, in 1994, no sewage was left totally untreated in the Ontario or Prairie communities with systems. However, more than 50% of the population of the Atlantic provinces with sewage systems were not served by any form of wastewater treatment. The situation in Quebec has changed sharply in recent years. As of 1994, 84% of the population with sewage systems also had treatment plants (compared with 56% in 1991), as a result of the recent construction of new wastewater treatment systems in Montreal and other cities. The treatment plant for the Montreal Urban Community became fully operational under normal conditions in August 1995, with treatment of peak period storm runoff expected by spring 1996.

In 1994, over three-quarters of the population served by systems in Ontario and nearly a third in the Prairie provinces were served by tertiary treatment, compared with minimum levels in the Atlantic provinces and low proportions in the other regions. In British Columbia and the Atlantic provinces, large volumes of wastewater, including the sewage of cities such as Victoria and Halifax, are discharged into the ocean untreated or after only primary treatment. In Quebec, 40% of the population with systems received primary treatment (Environment Canada 1994a, 1996b; Statistics Canada 1994). In some cases, these levels have adverse consequences for local shellfish grounds and coastal wetlands and shorelines. Combined systems that result in an overflow of sewage and stormwater drainage remain a problem that is expensive to remedy.

Energy

Canadians consume a lot of energy. Annual use of energy per person has declined slightly since its 1989 peak of 325 GJ (Statistics Canada 1994), but this may be partly a temporary consequence of the economic downturn of the early 1990s. In 1992, the transportation sector accounted for 30% of total energy consumption, whereas residential use accounted for nearly 20% — one of the consequences of the prevalence of the detached single-family house (Environment Canada 1994c).

Figure 12.15
Energy use per person by settlement pattern, in comparison with provincial and national values, 1988



Notes
1. Data are for end-use energy, which is a lower amount than total primary energy (see Chapter 11).
2. A 30-L gasoline fill-up contains about 1 GJ of energy.
3. City of Ottawa data are for 1990
4. Suburban Toronto represents Metropolitan Toronto excluding the City of Toronto.

Source: Torrie Smith Associates, Inc. (1994)

The production and consumption of fuels and electricity in cities lead to local and global environmental stresses. In particular, the combustion of fuels for automobile use, home heating, and commercial enterprises at highly concentrated levels in the city leads to local air pollution from emissions of nitrogen oxides, VOCs, sulphur dioxide, and particulate matter and contributes to global warming through the release of carbon dioxide. In addition, ecosystems both near and distant from the city experience environmental risk and ecological stress from the production, transport, and use of energy (see Chapter 11).

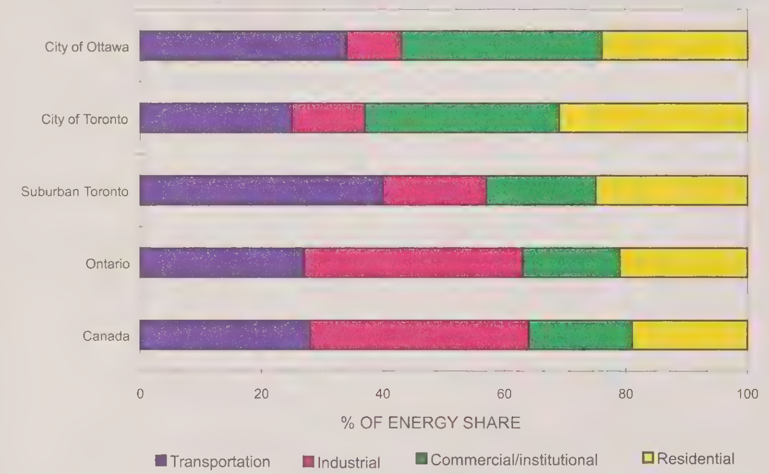
Are levels of energy use affected by urban population density or the spread-out nature of suburban development? Unfortunately, as in most other countries, information about electricity and fuel use is not compiled at the municipal level, which makes it difficult to develop a picture of urban energy use in Canada. Nevertheless, profiles of energy use have been undertaken in three large urban areas (Fig. 12.15) and may be compared with provincial and national energy use (Millyard 1992; Marbek Resource Consultants 1993a, 1993b; Torrie Smith Associates, Inc. 1994).

Although overall levels of energy use are high, per capita use of energy in the inner city (City of Ottawa, City of Toronto) is lower than in suburban areas (suburban Toronto) and lower still than in small-town and rural areas, as reflected in provincial and national energy use statistics. It seems that the inner city, given its higher population density — with more potential for multiple-family housing units and transit use — is a more energy-efficient form of settlement.

Most of the energy use in large Canadian cities is accounted for by the residential, commercial/institutional, and transporta-

tion sectors (Fig. 12.16). Industrial energy use, concentrated in primary resource extraction and processing industries, is typically not situated in large cities but is indirectly linked to them through trade and consumption. In the urban cores of Ottawa and Toronto, the commercial/institutional sector accounts for one-third of all energy use, which is double the national average and clearly a target for energy management. For example, extensive enclosed environments in the large cities make it possible for people to travel between their apartments and places of employment and attend to shopping, dining, and other personal business without ever going into the open air. This may be convenient and comfortable, but it requires heavy energy consumption for heating, cooling, and ventilating the system.

Figure 12.16
Sector share of energy by settlement pattern, in comparison with provincial and national values, 1988



Notes:
1. Data are for end-use energy.
2. City of Ottawa data are for 1990.
3. Suburban Toronto represents Metropolitan Toronto excluding the City of Toronto.

Source: Torrie Smith Associates, Inc. (1994).

Table 12.1
Total municipal end-use energy consumption in Ottawa, 1990

Sector	Energy consumption (TJ)				
	Natural gas	Electricity	Gasoline	Other oil products	Total
Residential	4 938	6 040	0	1 930	12 908
Commercial	7 747	9 110	0	759	17 616
Streetlights	0	115	0	0	115
Industrial	999	1 011	0	2 985	4 995
Transportation	25	0	13 198	4 973	18 196
Total[a]	13 710	16 276	13 198	10 648	53 832

[a] Values may not add up owing to rounding.

Source: Millyard (1992).

On a per capita basis, transportation energy use is less than the Canadian average in dense inner-city areas (e.g., City of Ottawa, City of Toronto) but higher than the national average in suburban areas (e.g., suburban Toronto). The dependence of suburban settlements on the automobile leads to particularly high transportation energy use in suburban and fringe areas (Torrie Smith Associates, Inc. 1994).

Calculations for the City of Ottawa indicate that electricity and natural gas are the energy sources of choice for the city's residential and commercial sectors (Table 12.1), whereas gasoline and other oil products provide the energy for the city's transportation sector. The industrial sector in the city derives energy from oil, electricity, and natural gas. Given this diversity of sources, energy use in each sector will have different environmental consequences and require different planning, management, and conservation strategies if cities are to make progress towards sustainability.

Materials use

Solid waste

The generation and management of solid waste are serious environmental, social, and economic issues throughout Canada. Moreover, from an ecosystem perspective, waste material constitutes a waste of energy and resources in itself. Much of the material that enters a landfill or an incinerator represents a resource that has not been fully used and that might have been reduced at source, reused, or recycled, thus lessening the need to extract and process new resources.

From an economic standpoint, dealing with solid waste is expensive: annual disposal costs, including collection, transportation, and landfill or incineration, are estimated at more than $3 billion (Resource Integration Systems Ltd. 1995), borne almost entirely by municipalities. This sum does not include environmental

or social costs or the costs represented by lost resources.

In community and environmental terms, waste disposal constitutes a continuing problem: existing landfills in Canada are being used up, and suitable new landfill sites accessible from the major sources of waste — the cities — are becoming harder to find and to have approved. Both landfilling and incineration are controversial and almost certain to raise vigorous local opposition. Although technology has improved significantly, neither landfilling nor incineration is free of environmental impacts. Landfills emit methane and other gases, some of which are toxic, and methods to capture and contain these gases are less than 100% efficient. If a landfill is inadequately engineered, leachates (leaking liquid) may contaminate surface water or groundwater. For its part, incineration emits toxic contaminants and particles into the air and leaves hazardous solid residues to be disposed of in specialized facilities. Nevertheless, pilot testing in Canada and elsewhere has shown that modern high-temperature incineration methods coupled with emission controls could largely solve air emissions problems (Environment Canada 1991). Ironically, the high volumes of waste required to make municipal incineration economical could provide a disincentive for municipalities to reduce, reuse, and recycle waste materials.

Canadians produce large quantities of municipal solid waste, from residential, institutional, commercial, and industrial sources. Although figures from different surveys and estimation methods vary somewhat, a reasonable estimate, based on Material Flow Analysis by Senes Consultants Ltd. and Franklin Associates Ltd. (1995), is 18.1 million tonnes of municipal solid waste in 1992, or 637 kg per person yearly (1.7 kg daily; Table 12.2), of which about one-half is from residential sources. Adding the construction and demolition waste stream, composed largely of waste from buildings, roads, and bridge work, brings the estimate of total solid waste in Canada in 1992 to 29.3 million tonnes, or 1 030 kg per person. Comparisons among countries are difficult owing to differences in definitions and in collection and data tabulation methods, but Canadians are typically cited among the leading per capita producers of municipal solid waste in the world (e.g., Corson 1995).

As a result, the Canadian Council of Ministers of the Environment has set a national target for reducing the amount of nonhazardous and hazardous solid waste disposed of annually. The target is a 50% decrease from 1988 levels on a per person basis by the year 2000. Early results show that Canadians are making progress in reducing their solid waste. Interpretation of results based on only two points in time is risky, but comparisons indicate that the generation of total solid waste per person in Canada declined by 16.2% from 1988 to

Table 12.2
Municipal solid waste and total solid waste, 1988 and 1992

Description	Municipal solid waste			Total solid waste		
	1988	1992	% change	1988	1992	% change
Population (000s)	26 895	28 436	+5.7	26 895	28 436	+5.7
Gross domestic product ($1988, millions)	605 906	658 219	+8.6	605 906	658 219	+8.6
Solid waste (t, 000s)						
Generated	17 968	18 110	+0.8	33 062	29 297	–11.4
Recovered	1 136	3 109	+173.7	7 644	8 717	+14.0
Discarded	16 832	15 001	10.9	25 418	20 580	–19.0
Solid waste (kg) per capita						
Generated	668	637	–4.7	1 229	1 030	–16.2
Recovered	42	109	+158.9	284	307	+7.9
Discarded	626	528	-15.7	945	724	–23.4
Solid waste (t) per $ million GDP						
Generated	29.7	27.5	7.2	54.6	44.5	18.4
Recovered	1.9	4.7	+151.9	12.6	13.2	+5.0
Discarded	27.8	22.8	-18.0	42.0	31.3	-25.5

Notes: 1. Municipal solid waste consists of residential, industrial, commercial, and institutional waste. It is defined as materials discarded by individuals in the course of their daily activities at home and by commercial businesses, industries, and institutions as a result of normal operating activities, not including liquid industrial waste or hazardous waste.
2. Total solid waste consists of municipal solid waste and construction and demolition waste.
3. Waste generated represents waste generated after reused quantities are deducted.
4. Waste recovered consists of materials, food wastes, and yard trimmings removed from the waste stream for the purposes of recycling and composting
5. Waste discarded consists of landfill and incineration.
6. Values may not add up owing to rounding

Source: Senes Consultants Ltd. and Franklin Associates Ltd. (1995).

Table 12.3
Where solid waste goes, 1992

Description	Municipal solid waste			Construction and demolition			Total solid waste		
	t (000s)	% of generation	kg/capita	t (000s)	% of generation	kg/capita	t (000s)	% of generation	kg/capita
Generation	18 110	100	637	11 187	100	393	29 297	100	1 030
Recovery for recycling	2 696	14.9	95	5 607	50.1	197	8 303	28.3	292
Recovery for composting	413	2.3	15	0	0	0	413	1.4	15
Total recovery	3 109	17.2	109	5 607	50.1	197	8 717	29.8	307
Incineration	899	5.0	32	incl. in MSW	n/a	n/a	899	3.1	32
Disposal to landfill, other	14 102	77.9	496	5 579	49.9	196	19 681	67.2	692
Total discards	15 000	82.8	528	5 579	49.9	196	20 580	70.2	724

Notes: 1. Municipal solid waste (MSW) consists of residential, industrial, commercial, and institutional waste.
2. The term "diversion" is often used in the literature instead of "recovery."
3. Values may not add up owing to rounding.

Source: Senes Consultants Ltd. and Franklin Associates Ltd. (1995).

1992, whereas the discard of solid waste decreased by fully 23.4% per person over the four-year period (Table 12.2). Slightly greater percent declines in both waste generated and waste discarded were recorded on a per unit value of gross domestic product (GDP). These trends parallel the 21% reduction in packaging in Canada reported by the National Packaging Monitoring System for the same period (CCME 1993). Although progress in reduction of total solid waste is tempered by the fact that the significant declines in construction and demolition waste as well as industrial and packaging waste were likely caused, in part, by the economic recession of 1990–1992, progress towards the national goal is being made.

For municipal solid waste alone, the trends from 1988 to 1992 are less significant but are generally in the right direction and may prove longer lasting. Overall, the generation of municipal solid waste increased slightly over the four-year time span, but the discarding of municipal waste declined by nearly 11%, largely because of impressive increases (173.7%) in recycling and composting by municipalities, households, and businesses. Per capita and per unit of GDP trends for municipal solid waste indicated even larger declines in wastes generated and discarded.

Although major gains occurred in the recycling and composting of municipal solid waste between 1988 and 1992, owing to the efforts of cities, consumers, and producers, the challenge to reduce the waste stream even further remains. Nearly 83% of municipal solid waste generated in 1992 was discarded: 78% to landfill sites, and 5% to incineration. Meanwhile, 17% was recovered by recycling and composting (Table 12.3) — up from 6% in 1988. Because of the 50% recycling rate of construction and demolition waste (largely of asphalt and concrete), the overall recovery rate of total solid waste generated in Canada in 1992 reached nearly 30%.

The main materials (by weight) in municipal solid waste generated in 1992 were paper and paperboard (25%), food wastes (19%), yard wastes (13%), and plastics (12%). Sizeable quantities of metals, wood, and glass were also recorded (Fig. 12.17). The composition of the municipal waste stream was virtually unchanged from 1988, with small increases reported for metal and wood waste and a modest decline in glass waste, reflecting changes in production methods and consumer preferences. Asphalt dominated the materials generated in the construction and demolition waste stream in 1992, at nearly 35% of the total, followed by concrete, rubble, and wood — an indication of the prominent role of transportation infrastructure in cities.

Although the recycling and composting of virtually all municipal solid waste materials increased from 1988 to 1992, the level of recovery and the rate of increase varied greatly from one material to another (Fig. 12.18). Highest levels of recovery were for metals, paper and paperboard, and glass (although none exceeded 40%), with metals showing the most dramatic increase in recovery rate. Recycling of plastics and wood from the municipal solid waste stream, virtually nonexistent in 1988, had been initiated by 1992 but remained at low levels. Similarly, municipal and individual composting of yard waste (10.5%) and food waste (2.2%) as of 1992 left substantial room for improvement. Variation in the recycling or composting of waste materials reflects differences in the availability and accessibility of community recycling, markets for manufacturing and postconsumer wastes, the effectiveness of recycling technologies, and the level of awareness of consumers, businesses, and institutions and their willingness to recycle.

Residential or household solid waste collected for disposal (municipal solid waste without industrial, commercial, and institutional waste) varies considerably by region and by size of municipality across Canada (Cameron 1995; Statistics Canada 1995b). Large and medium-sized municipalities (30 000 population and over) reported average collection of slightly over 300 kg per person annually, whereas smaller municipalities (5 000–29 999 population) averaged 415 kg per

person. Based on a survey of 642 municipalities of 5 000 population or more, Statistics Canada (1995b) reported that the amount of residential waste collected for disposal showed substantial regional variation, with the lowest per capita rates recorded in British Columbia and the highest in Quebec and Atlantic Canada. The report cautioned, however, that "regional variation . . . is likely related to both the administration of municipal waste management in those areas and the average population density [size] of surveyed municipalities" — which was smaller in Quebec and the Atlantic provinces.

Management of solid waste presents a serious challenge to Canada's cities. Waste reduction, reuse, recycling, and composting initiatives that demonstrate progress towards sustainability are highlighted later in the chapter.

Contamination of land by waste

A particular form of waste has emerged as an important urban environmental problem. Some old industries, repair shops, garages, and similar operations have left their sites so contaminated with materials spilled, dumped, or leaking from underground storage tanks that they cannot safely be redeveloped for residential, recreational, or even commercial use without a costly cleanup. "Even though potentially toxic industries may have closed down years ago, certain compounds . . . and metals (lead, cadmium, chromium, nickel) can persist in the soil for hundreds of years" (City of Toronto 1993).

Land contamination is now seen as a serious obstacle to the redevelopment or reuse of centrally located sites. Perhaps the outstanding example is the fate of the Ataratiri project, a scheme by the City of Toronto and the Ontario government to create a new neighbourhood comprising up to 7 000 dwellings, together with light industry, on 30 ha of largely abandoned industrial land close to downtown Toronto. The scheme was dropped, in large part because of the cost of cleaning up the site, estimated in 1988 as $32.5 million (Government of Ontario and City of Toronto 1988). Similar problems were encountered in the redevelopment of the Expo site on Vancouver's False Creek. The problem is not, however, confined to big cities; for example, the soil of mining towns such as Trail, B.C., may be contaminated by the deposition of lead-containing dust from smelters (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993).

Chemical fertilizers and pesticides can be regarded as another form of land contamination. Frequently used domestically, they enter the ecosystem by either leaching into the ground or entering the wastewater disposal system (Statistics Canada 1995a). In response, many municipal governments no longer apply herbicides to parks and other public lands.

Some cities have traced and recorded contaminated land within their own boundaries (Campbell et al. 1994); however, as there is neither a national inventory of such sites nor any generally accepted standards, the full extent of the problem in Canada is unknown.

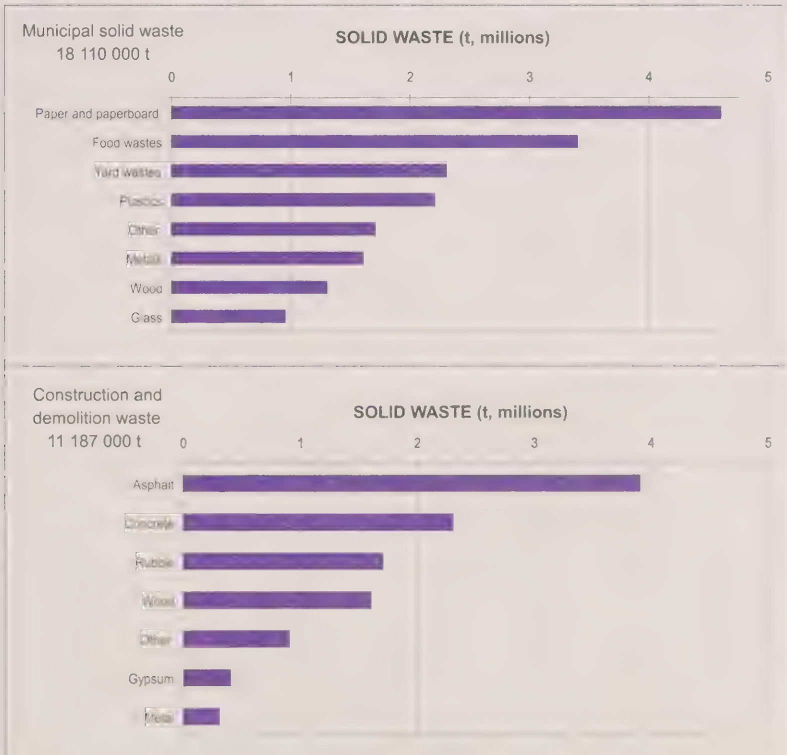
Land

Nature in the city

Until recent decades, green space in the city — defined as "wooded and non-wooded vegetated areas [and] vegetated wetlands" (Carruthers 1994) — was seldom considered to have any value other than for building on or for serving some other utilitarian purpose. Thus, many water-

Figure 12.17

Materials in the solid waste stream, 1992



Notes: 1. Municipal solid waste consists of residential, industrial, commercial, and institutional waste.
2. Other municipal solid waste consists of rubber and leather, textiles, miscellaneous inorganic wastes, and other
3. Other construction and demolition waste consists of paper, building material, and other

Source: Senes Consultants Ltd. and Franklin Associates Ltd. (1995).

courses became storm sewers; stream valleys and other natural areas were seen as convenient locations for dumps and highways; and waterfronts were given over to industries, railways, and roads.

Parks were regarded almost exclusively as recreation areas. However, when they replace features such as productive wetlands, parks can be just as destructive of the natural environment as streets and buildings (Richardson 1994b). Much park space is given over to sports and playgrounds, whereas a large share of the remainder is devoted to manicured lawns, flower beds, and other ornamental plantings, often dominated by exotic species. Golf courses and formal parks have usually been irrigated and treated with fertilizers and pesticides, eliminating whatever remained of their natural characteristics and adding polluted runoff to water bodies and watercourses.

Thus, although it provides important social benefits, much urban outdoor recreation space has little conservation or environmental value apart from some reduction of surface runoff. Even the "wild" areas that have been preserved, as in Vancouver's Stanley Park, are so heavily used that their original natural characteristics have been severely eroded.

Nevertheless, nature is never driven out of the city altogether and, with some encouragement, will restore its own ecosystems within the urban fabric. Wildflowers and even saplings will soon return to a vacant site. Despite the elimination of much of their natural habitat, some wildlife species have displayed a tenacious ability to survive and even flourish in the urban environment, aided by parks, street trees, backyards, and the many other remaining green areas, including landfill sites.

Vegetated areas within the city, such as woods and ravines, provide habitat for a variety of plants and wildlife, moderate the urban microclimate, decrease air pollution by trapping particles and absorbing carbon, reduce storm flows that might otherwise overload sewers and treatment plants, and help to prevent soil erosion (City of Ottawa 1993).

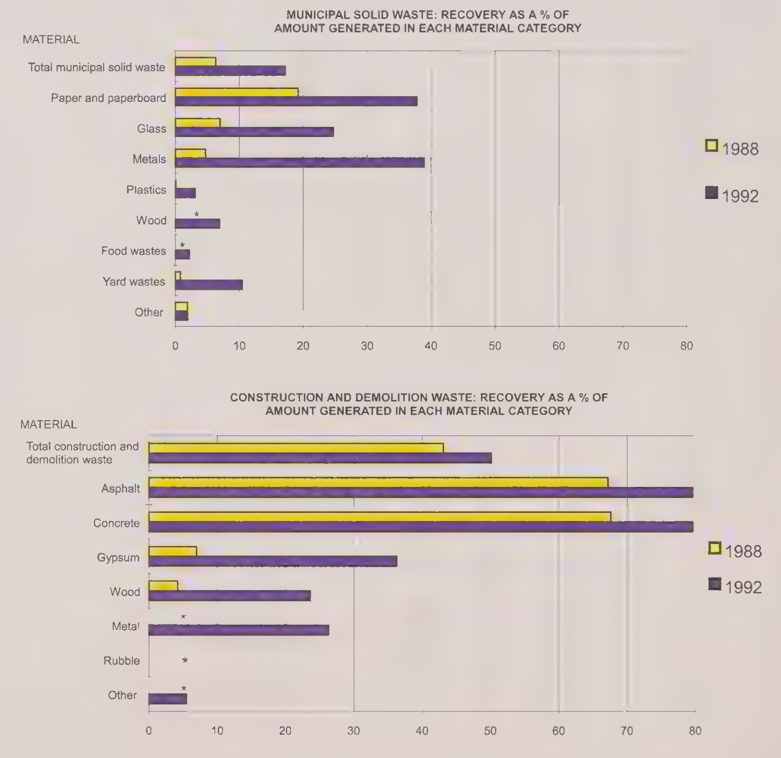
Urban green spaces offer recreation and education opportunities, afford citizens a sense of freedom and relaxation, provide contact with nature and aesthetically pleasing surroundings, lend structure and pattern to the urban form, and create economic spinoffs (GVRD 1992; Carruthers 1994).

The growth of "environmentalism" in the 1960s ushered in a new appreciation of the ecological importance of green space. "The conservation movement . . . brought with it . . . a new strategy for dealing with environmental conditions called the 'ecosystem approach.' This holistic approach regarded green spaces not as individual pockets of green, isolated in a built environment, but as a functioning system with collective impacts on environmental and social elements of the city" (Carruthers 1994).

With the rise of the ecosystem approach to environmental issues, the notion of a natural heritage system has gained increasing acceptance. This envisions a network of connected green areas that allows for the reproduction and migration of a wide variety of plant and animal species within the urban area. In its most advanced form, this ecosystem perspective sees the natural

Figure 12.18

Recovery of solid waste by recycling and composting, by material category, 1988 and 1992



Notes: 1. The term "diversion" is often used in the literature instead of "recovery."
2. Municipal solid waste consists of residential, industrial, commercial, and institutional waste.
3. Other municipal solid waste consists of rubber, leather, textiles, and other.
4. Other construction and demolition waste consists of paper, building material, and other.
5. An asterisk (*) indicates 0%.

Source: Senes Consultants Ltd. and Franklin Associates Ltd. (1995).

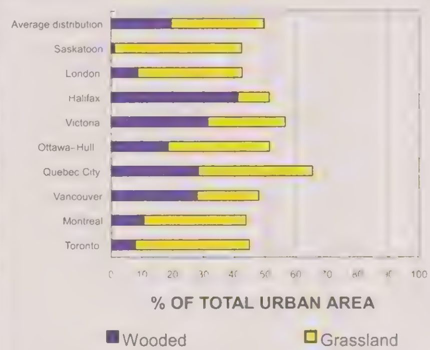
heritage system as the arena in which the development and evolution of the city take place, rather than as a backdrop to development activities (Tomalty et al. 1994). Such activities are then moderated to maintain, strengthen, or expand the natural heritage system.

Green space in Canadian cities

Reliable generalizations about trends with respect to urban green space are not possible in the absence of common standards and criteria and a national green space inventory. Nevertheless, a partial snapshot of green space in selected Canadian cities as of 1991 has been developed through the interpretation of satellite imagery based on a methodology developed in a pilot study of Ottawa–Hull (Statistics Canada and Environment Canada 1993).

As Figure 12.19 shows, total green space encompassed on average nearly 50% of the urbanized core (continuously built-up area) of the nine selected centres, or almost 34 ha per 1 000 population. On a per person basis, the green space available was lowest in the large urban areas of Toronto and Montreal. The amount of wooded green space tended to reflect the ecosystem in which the cities were situated, being highest in Halifax, Vancouver, Victoria, and Quebec City and lowest in the Prairie and southern Ontario cities of Saskatoon, London, and Toronto. Overall, nearly 90% of the parcels of green space were less than 10 ha in size; in fact, over 40% were under 1 ha — the size of an average suburban schoolyard (Table 12.4). Less than 4% of parcels covered more than 50 ha. In this analysis, green space encompassed all natural areas within the city regardless of use or condition, including parcels in industrial parks, university cam-

Figure 12.19
Green space in selected urban areas, 1991



URBAN AREA	TOTAL GREEN SPACE[a] (ha)	TOTAL GREEN SPACE PER 1 000 POPULATION (ha)
Average distribution		33.9
Saskatoon	6 481	30.9
London	9 588	25.1
Halifax	12 375	38.6
Victoria	14 500	50.4
Ottawa–Hull	28 737	31.2
Quebec City	35 471	54.9
Vancouver	54 169	33.8
Montreal	68 830	22.0
Toronto	71 994	18.5

[a] Total green space = wooded + grassland area

Notes: 1. Minimum size area for green space to be included is 30 m².
2. Data are provided for the urbanized core of the census metropolitan area. "Urbanized core" is according to the Statistics Canada (1992a) definition.
3. Population data are derived from Statistics Canada (1992a)
4. Original calculations included areas of water, which have been excluded from this figure
5. Urban areas are listed according to the total area of green space

Source: National Urban Land Information Base, Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, and State of the Environment Directorate, Environment Canada

Table 12.4
Green space in selected urban areas, by size of parcel, 1991

	No. of green space parcels								Total	Total	Total
	<1 ha		1–9.99 ha		10–49.99 ha		≥50 ha		no. of	green space	urban
Urban area	No.	%	No.	%	No.	%	No.	%	parcels	area (ha)	area (ha)
Toronto	1 967	44.5	2 061	46.7	264	6.0	125	2.8	4 417	71 994	160 338
Montreal	1 921	46.1	1 855	44.6	268	6.4	120	2.9	4 164	68 830	157 196
Vancouver	1 150	46.1	1 101	44.1	180	7.2	66	2.6	2 497	54 169	113 058
Ottawa–Hull	573	40.5	679	48.0	97	6.9	65	4.6	1 414	28 737	55 773
Quebec City	500	50.9	398	40.5	56	5.7	29	2.9	983	35 471	54 246
Victoria	382	51.8	312	42.4	26	3.5	17	2.3	737	14 500	25 605
Halifax	160	32.1	273	54.7	42	8.4	24	4.8	499	12 375	23 923
London	155	32.6	245	51.6	46	9.7	29	6.1	475	9 588	22 523
Saskatoon	107	33.6	172	53.9	23	7.2	17	5.3	319	6 481	15 366
Average % distribution		42.0		47.4		6.8		3.8			

Notes: 1. Data are for the urbanized core of the census metropolitan area.
2. Green space includes wooded and grassland areas.
3. Original calculations included areas of water, which have been excluded from this table

Source: National Urban Land Information Base, Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada; and State of the Environment Directorate, Environment Canada

puses, freeway interchanges, vacant areas, and cemeteries, as well as formally designated parks, sports fields, and floodplains.

Despite the new appreciation of urban green space, parcels of green space tend to remain under constant threat, and city land use controls are not always strong enough to guarantee them permanent protection. "Unused" or "underused" land remains a temptation both to private developers and to public agencies seeking sites for necessary buildings and facilities. The move towards urban "intensification" — increasing the intensity of occupancy of urban land with a view to reducing infrastructure costs and increasing energy efficiency — will, whatever its merits, place additional pressure on green space. There are undoubtedly trade-offs. An enlarged green space system within the city may lead to new residential areas being located on rural land at the city's edge beyond the protected green space, thus increasing the length, costs, and energy consumed for services such as streets, water mains, and sewers.

Consumption of land
Between 1966 and 1986, the growth of Canadian cities with populations of more than 25 000 occupied over 3 000 km^2 or 300 000 ha of rural land (Table 12.5). Although a large share of this total area converted to urban uses was accounted for by the nine largest cities (42.9%), smaller urban centres, with populations of between 25 000 and 50 000, actually occupied nearly four times more land per capita: 196 ha for each 1 000 people added, versus 50 ha per 1 000 for the large cities (Fig. 12.20).

There is no reason to believe that the rate of urban land occupation has substantially declined since 1986. A pilot satellite imagery study of the Vancouver metropolitan area for the 1986–1991 period revealed an increase in the urban built-up area of nearly 4 400 ha, or 6% (Statistics Canada and Environment Canada, National Urban Land Information Base, unpublished data). These preliminary results compare with a conversion rate of rural land to urban use of 4.4% over the 1981–1986 period (Environment Canada, Canada Land Use Monitoring Program, unpublished data) and 7.9% over the 1971–1976 period in the same area (Warren and Rump 1981).

Given the inevitability of continuing growth in the urban population in the coming decades, urban expansion can only continue. A 1990 study concluded that by the year 2021, even assuming the most compact pattern considered feasible, the total urbanized area of the Greater Toronto Area as of 1988, 1 520 km^2, would grow by 350 km^2, or 23%. With the most dispersed pattern — in effect a continuation of current trends — the increase would be 900 km^2, or 59% (IBI Group 1990).

This rate of land occupation is largely due to an urban form shaped by the popularity of the detached, single-unit house surrounded by its own lot. In a suburb built after the Second World War, one household accounts for two to five times as much land, including the land taken up by streets and such uses as schools,

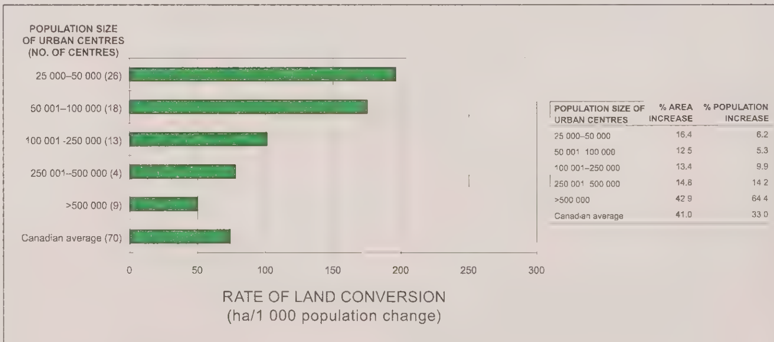
Table 12.5
Total rural land and prime agricultural land converted in Canadian urban centres, 1966–1986

Province (no. of centres)	Total rural land area (ha)	Prime agricultural land	
		Area (ha)	% of TRL
British Columbia (7)	45 330	9 360	21
Alberta (5)	51 691	31 429	61
Saskatchewan (4)	10 613	6 918	65
Manitoba (2)	13 046	11 447	88
Ontario (26)	105 952	83 040	78
Quebec (19)	50 587	24 912	49
New Brunswick (3)	10 848	2 425	22
Nova Scotia (2)	8 043	3 047	38
Prince Edward Island (1)	2 280	2 197	96
Newfoundland (1)	3 050	15	<1
Total (70)	301 440	174 790	58

Notes: 1. Urban centres over 25 000 population as of 1966.
2. TRL: total rural land.

Source: Warren et al. (1989).

Figure 12.20
Urbanization of land: rate of land conversion by population size of urban centre, 1966–1986



Note: 1986 is the last year for which Canada-wide data are available.
Source: Warren et al. (1989).

parks, and shopping, as a household in a centrally located neighbourhood built before the First World War. Retail business and industry have also contributed to low-density development. Municipal zoning standards and curvilinear street patterns, replacing the traditional grid layout, have reinforced the spread-out form of urban development.

The single detached house does not appear to be losing its popularity. In Canadian urban areas with more than 10 000 people, the proportion of housing starts for single detached homes actually rose from 31.4% in 1971 to 44.5% in 1981 and again to 52.8% in 1994, with a peak at 57.0% in 1986 (Table 12.6). Even in metropolitan areas, approximately one-half of total housing starts in 1986, 1991, and 1994 were single detached houses, although there was considerable variation across the country: the proportion was substantially higher for Prairie cities and somewhat lower for west coast and most Quebec centres. However, the average densities of new residential developments are increasing in many metropolitan areas, in part because single-family detached lots have contracted from the typical 50- to 60-foot (approximately 15–18 m) lot frontages of the 1970s to 30- to 40-foot (approximately 9–12 m) lot frontages in the 1990s.

Despite Canada's vast size, only about 5% of its total land area is capable of producing a range of crops (Canada Land Inventory 1976). As settlers generally sought land that could be farmed, much of the expansion of the original settlements took place on fertile agricultural land. The trend continues to this day. Fully one-quarter of Canada's high-capability class 1–3 agricultural land lies within 80 km of the 23 largest cities, whereas more than half the country's prime (class 1) agricultural land is located in this near-urban area (Neimanis 1979).

Overall, the direct "loss" of agricultural land to urban growth appears quite modest. However, gross area figures do not take two important factors into consideration. First, in some parts of Canada, urbanization affects specialty crop areas that account for only a tiny proportion of the total amount of productive land. Outstanding examples are Ontario's Niagara Peninsula, British Columbia's Okanagan Valley, and the horticultural areas adjacent to Montreal and Vancouver (Environment Canada 1979; Kerr et al. 1985; Bond 1988). In such areas, the agricultural impacts of urbanization are far more significant, hectare for hectare, than they are in the country at large.

Second, agriculture is affected by urban growth in many less direct ways. Urban expansion, including the extensive industrial sites, gravel pits, golf courses, recreational facilities, and residential estates that dot the landscape around Canadian cities, has substantial economic and social impacts on surrounding agricultural regions. These "urban shadow" effects extend over much greater areas than the physical change would indicate, leading to a corresponding decline of agriculture in the urban region (Gertler et al. 1977). This process feeds itself: if long-term, viable agriculture is discouraged even on land that is not needed for urban growth, it is more likely to be replaced by miscellaneous nonagricultural uses, or the land may even be abandoned (McCuaig and Manning 1982). In response, some provinces have adopted policies regulating urban expansion in agricultural areas, whereas others (e.g., Quebec and British Columbia) have had protective agricultural zoning in place for some time.

Fears over the loss of farmland to urban growth can oversimplify what is in fact an extremely complex set of interlocking issues, embracing a range of social and economic factors. Nevertheless, there is much reason for concern about the consequences of urban growth for agriculture in Canada.

Furthermore, the adverse effects of the spread of the city into its rural hinterland

Table 12.6

Urban housing starts by type of dwelling, 1971–1994

	1971		1976		1981		1986		1991		1994	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Census metropolitan areas												
Single detached	41 851	28.2	62 044	38.0	49 277	43.9	77 604	56.5	49 642	49.1	50 645	51.0
Semidetached	8 712	5.9	10 264	6.3	8 630	7.7	5 509	4.0	6 311	6.2	8 056	8.1
Row	12 634	8.5	26 400	16.2	12 079	10.8	8 290	6.0	12 902	12.8	12 946	13.0
Apartments and other	85 240	57.4	64 521	39.5	42 178	37.6	46 030	33.5	32 253	31.9	27 703	27.9
Total	148 437	100.0	163 229	100.0	112 164	100.0	137 433	100.0	101 108	100.0	99 350	100.0
All urban areas >10 000												
Single detached	56 887	31.4	85 301	40.7	63 383	44.5	97 341	57.0	66 014	50.7	67 285	52.8
Semidetached	10 962	6.1	13 682	6.5	10 269	7.2	7 060	4.1	8 213	6.4	10 799	8.5
Row	14 279	7.9	30 717	14.6	14 069	9.9	9 880	5.8	15 910	12.2	15 543	12.2
Apartments and other	98 820	54.6	80 062	38.2	54 720	38.4	56 582	33.1	39 957	30.7	33 719	26.5
Total	180 948	100.0	209 762	100.0	142 441	100.0	170 863	100.0	130 094	100.0	127 346	100.0

Source: Canada Mortgage and Housing Corporation (various years).

are not confined to agriculture. Woodlands and other natural growth are removed, wildlife corridors are disrupted and habitat is destroyed, and soil erosion is accelerated. Wetlands are filled or drained: by 1981, up to 98% of the original wetlands in the vicinity of Regina, Winnipeg, and Windsor had been converted to other uses; the proportion was 88% in the vicinity of Toronto and Montreal, and nearly 78% in the vicinity of Vancouver, Calgary, and St. Catharines–Niagara Falls (Environment Canada 1988). Environmentally sensitive areas are threatened and sometimes destroyed. Groundwater may be drawn down, and groundwater, water bodies, and streams may be polluted by storm runoff and by septic tank and landfill seepage; aquatic habitat is destroyed or impaired. Air quality is affected by gravel pits, landfills, and the continuous truck traffic they generate.

Although most of these diverse ecological impacts might not occur if cities did not grow, it is nevertheless misleading to view them as the "inevitable" consequences of urban growth. To a large extent they could be avoided, or at least greatly mitigated, by strict control and careful planning of land use to achieve a tighter, more structured urban form. The issue is not so much urban growth in itself as the way in which growth is managed — or not managed.

Finally, it should be noted that the direct consumption of rural land as built-up area by the city and the "urban shadow" effects that occur in surrounding rural areas as a result of urban expansion are significant issues, but they are only a part of the functional land demand of the human activities in the city, "the ecological footprint" of its residents (see Chapter 1). For example, the 1.6 million inhabitants of the Greater Vancouver Regional District "appropriate" the productive output of a land area 23 times larger than the actual geographic size of the Vancouver metropolitan area (2 930 km²) to support the demand of people for food, forest products, and energy and to assimilate the wastes resulting from their activities (Rees 1996).

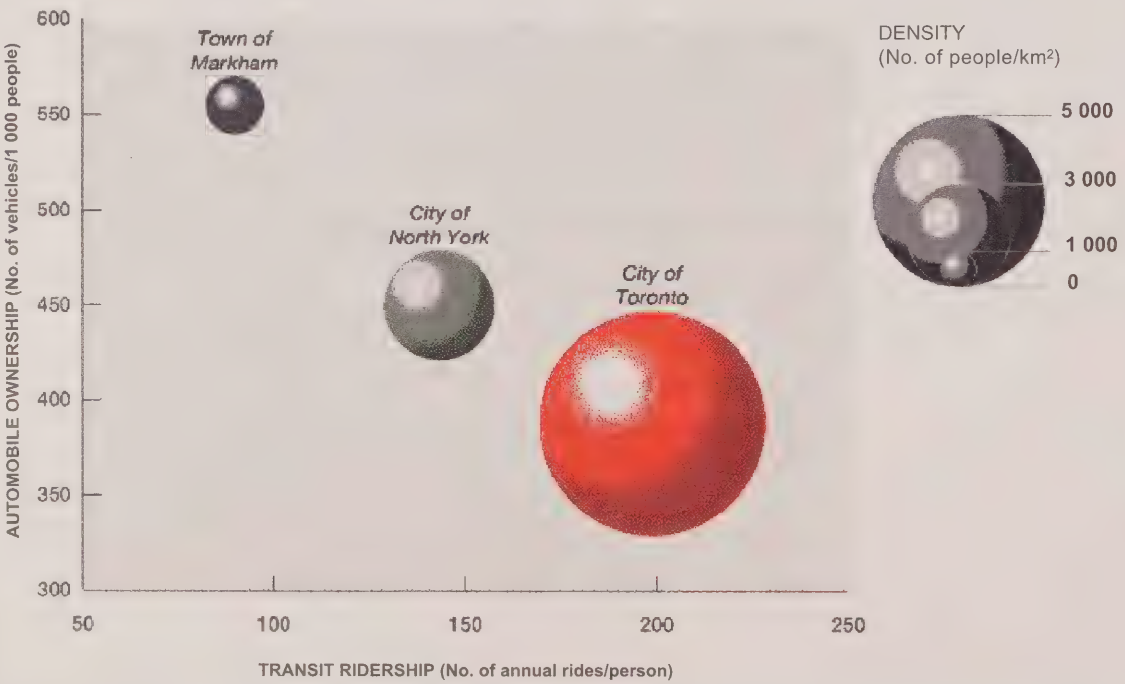
The role of the automobile

The widespread use of the automobile has dramatically influenced the form of Canadian cities and numerous environmental conditions, from land consumption and housing to energy use, air quality, and even climate change.

While Canada's population has doubled in the postwar years, car ownership has multiplied many times over. Rising ownership

Figure 12.21

Urban form and its relationship to transportation, Greater Toronto Area, 1992



Source: IBI Group (1993a).

and use of private cars and the sprawling form of the suburbs are trends that reinforce each other. Low densities, coupled with arterial roads unsuited to pedestrians and looping local streets unsuited to transit, have meant that transit service could not be provided economically. Thus, the new suburbs, shaped by the car, are dependent on the car, because alternative means of transportation are largely impractical. One car per household is almost indispensable; two or even more are not unusual. In the Toronto area, as shown by Figure 12.21, both population density and transit ridership drop and car ownership rises as one moves outward from the City of Toronto, developed primarily in the early 20th century and before, through the City of North York, which experienced rapid growth in the 1950s and 1960s, to the currently fast-growing Town of Markham.

The effects of continuing population growth have been reinforced in recent decades by an increase in the number of two-income families and by an aging, generally more affluent population, both tending to increase per-household car ownership and use. Despite the construction of successful subway systems in Montreal and Toronto, urban transit systems in Canada have been trapped in a downward spiral of revenues and ridership for most of the postwar period (see Fig. 12.8).

As well, during the 1950s and 1960s, electric streetcars were largely replaced by diesel buses, which were then seen as more flexible and cheaper to operate. The result was a decline in transportation energy efficiency and a corresponding increase in atmospheric emissions. More recently, however, the banning of leaded gasoline and greatly improved automobile fuel efficiency have substantially reduced per-vehicle emissions. As a result, total vehicular emissions of major atmospheric pollutants actually fell between 1985 and 1990, probably contributing to the improvement of air quality in Canadian cities (Environment Canada 1993). Nevertheless, this favourable trend has been partly offset by rising rates of car ownership and increased annual mileage per vehicle. Moreover, recent projections suggest that if the growth in automobile use is not moderated, total vehicle emissions will trend increasingly upwards as technological improvements to reduce vehicle emissions and fuel consumption per vehicle are overtaken by continuing growth in kilometres travelled annually per vehicle (IBI Group 1995).

The widespread ownership and use of private cars have unquestionably brought important social and economic benefits. They have also contributed significantly to resource depletion and environmental degradation (Environment Canada 1993). Their manifold impacts include the use of large quantities of energy and nonrenewable resources in automobile manufacture, the use of productive land for highways, the effects of road salt and other surface pollutants, the consumption of fossil fuels and accompanying air pollution, the emission of ozone-depleting CFCs from air conditioners, and the problem of disposing of old tires and used engine oil.

These effects are not confined to the cities, but cities are particularly affected by the car in two ways. First, as the number of vehicles increases and the number of kilometres driven annually rises, air pollution, ground-level ozone in particular, remains a problem, despite the reduction in per-vehicle emissions. The car is a leading contributor of ozone's precursors, i.e., nitrogen oxides and VOCs. A 1985 survey of national air emissions showed that gasoline-powered cars contributed 18.7% of total nitrogen oxide emissions, 22.9% of total VOC emissions, and 37.1% of total carbon monoxide emissions (Kosteltz and DesLauriers 1990). These emissions are heavily concentrated in urban areas, with the consequences that have been discussed. Cars also constitute a major source of "greenhouse gases," particularly carbon dioxide. With rising car ownership and use (combined with generally growing traffic congestion, which reduces fuel efficiency), these impacts are likely to increase in future years, despite improvements in technology and measures to encourage the use of other modes of transportation.

The automobile's second great impact on cities has been its effect, discussed above, on land use and urban structure. It is essentially the car, reinforced by demographic and economic factors, that has fundamentally changed the form of Canadian cities, allowing a diffuse, low-density pattern to spread around the older, compact urban area. In this way, the environmental impacts of the car, particularly air pollution, have been multiplied and extended.

Some suggest that attaining substantial improvements in the urban environment will call for large reductions in the use of the car in its present technological form. One study has even concluded that a completely car-free city is "desirable, feasible, and even necessary" (Canadian Urban Institute 1994). Whether or not this is the case, there are many measures that can be taken to reduce the dependence on cars in the city.

The following part of the chapter looks at the actions being taken to pursue these alternatives and to address other environmental issues in Canadian cities. The chapter concludes by examining the fundamental question of the city's environmental sustainability.

Towards a More Sustainable City

To what extent are Canadian cities environmentally sustainable? Can they be made more sustainable than they are, and, if so, are they in fact moving in that direction? To try to answer these questions, it is necessary to consider what the concept of environmental sustainability means, as applied to cities.

Cities and sustainability

At the time the earliest European settlements were established in Canada, they — and to an even greater extent the neighbouring Aboriginal villages — had to be largely self-sufficient in food, fuel, and many of the other necessities of life. Both communities were small and could sustain themselves within the carrying capacity of the local ecosystem without irreversibly degrading or depleting it.

This state of affairs changed radically as farming and lumbering expanded, as settlements grew into towns, then into cities, and as the demands of their populations multiplied. By 1987, the Brundtland Commission found that "These cities [of the industrialized world] account for a high share of the world's resource use, energy consumption, and environmental pollution. Many have a global reach and draw their resources and energy from distant lands, with enormous aggregate impacts on the ecosystems of those lands" (World Commission on Environment and Development 1987).

The evolution of the economy is driving Canadian cities even further in this direction. In step with the reduction of barriers to international trade and the "globalization" of national economies, Canada's urban consumers increasingly rely on many countries around the world to satisfy their demands for foodstuffs and goods in general.

However, it is important to recognize the distinction between the resource demands and environmental effects of *cities*, caused by density, form, and structure, and those of *people and their activities*. Canada's "ecological footprint" comprises the demands of Canadian society as a whole on the global supply of resources. It is both legitimate and useful to ask whether human activities are more or less sustainable in cities than in other places and whether and how cities can be made more sustainable, in the sense of imposing less stress on the ecosystem as a whole.

Furthermore, it is necessary to consider the sustainability of the city in relation to the goal of sustainable development. The city returns to the continental and global ecosystems not only a multitude of manufactured and processed material goods, but also a vast array of intangible services — ideas, knowledge and innovations, educational and cultural activities — that play their own part in the ecosystem. A city's role in sustainable development is not to attempt to be wholly self-sufficient within its own municipal boundaries, but to meet the needs of society while maintaining "a level of resource use and waste generation that is compatible with ecological sustainability within its region and no overall loss of environmental capital within the nation and the planet" (Mitlin and Satterthwaite 1994).

Such a city must be able to perform the economic functions that are the basis of its existence, and it must change, evolve, and develop to meet social as well as economic needs. Furthermore, a city that is not prosperous cannot build water and sewage treatment plants, preserve open spaces, or clean up contaminated land, and its citizens are unlikely to place the condition of the environment at the top of their priority list. In short, efforts towards environmental protection and resource conservation must recognize the city's need for continuing economic and physical development and revitalization.

In fact, a strong case can be made that cities are better for environmental protection and resource conservation than dispersed patterns of settlement. Potentially, at least, the city permits economies and efficiencies in the provision of water, sewage, and waste disposal (including recycling and reuse); in energy use (through, for example, district heating); and in the use of land (through compact development). The city also provides opportunities to substitute walking, bicycling, and transit for car use (Mitlin and Satterthwaite 1994).

Finally, regardless of whether it is possible for a city to be *absolutely* sustainable, it is undoubtedly possible for it to be *more* sustainable or *less* sustainable; in practical terms, that is the issue that needs to be addressed. In this practical sense, "Sustainable urban development . . . means the continuing maintenance, adaptation, renewal and development of a city's physical structure and systems and its economic base in such a way as to enable it to provide a satisfactory human environment with minimal demands on resources and minimal adverse effects on the natural environment" (Richardson 1992).

Obstacles to urban sustainability

There are, however, serious obstacles on the road to the "sustainable city."

Need for a long-term perspective

Urban sustainability is not a clearly defined, concrete objective to be reached by a certain deadline. It is an idea, a vision, to be used as a guide for sustained, multifaceted efforts over an indefinite period. It demands a long-term, comprehensive, and integrated perspective. For many people, including some politicians and public officials, these are new and difficult ideas, and they constitute an approach to urban management that does not fit well with traditional political and administrative systems. An issue of long-term, fundamental importance can easily be obscured by the apparently urgent immediate problem.

Inadequate knowledge

Much information is still lacking. Examples include uncertainties as to the long-term consequences of climate change; the implications of some air and water pollutants for human and ecosystem health; and the question of what residential density, and in what physical form, provides the optimal balance of environmental, social, and economic values. The knowledge that is already available may not be well used or fully shared. However, incomplete knowledge does not justify inaction.

Social and demographic factors

Environmental impacts in the urban setting are the cumulative products of millions of daily individual decisions, which are themselves, in part, the result of the demographic and cultural makeup of the population. Although their long-term implications are unclear, social and demographic factors that are likely to have significant consequences include:

- the general resistance to change resulting from ingrained social values, attitudes, and aspirations, particularly when personal economic interests or lifestyles are seen to be affected;

- a continuing attachment to the single-family detached house and the car and a corresponding mistrust of high- and even medium-density housing; and
- the relative growth of the oldest, relatively prosperous, sector of the population, which could reinforce general resistance to change and militate against increased transit use (Bussière and Dallaire 1994).

In short, urban growth and change in Canada are more responsive to economic demand and popular preferences in housing than to either long-term environmental sustainability or the infrastructure and social costs borne by the community as a whole.

Physical and cost factors
As most buildings and infrastructure are long lasting, the urban fabric has a great deal of built-in inertia and evolves slowly. Rapid and radical change may be disruptive and costly in social as well as financial terms, as became apparent in the era of urban renewal and expressway building a generation ago. In present fiscal circumstances, this kind of change is unlikely to be contemplated. Even providing such infrastructure as sewage treatment plants and rapid transit is very expensive.

Moreover, urban development is strongly influenced by technical and design codes set and maintained to achieve objectives (such as traffic flow or ease of maintenance) that typically do not include social or environmental considerations (Lefebvre et al. 1995).

Governance
Urban governance in Canada — the system of political control and administration of cities — is in many respects poorly suited to the pursuit of sustainability.

Of the three orders of government — federal, provincial, and municipal — the last (including metropolitan or regional municipal federations) has the most limited powers and resources. Thus, pursuing policies oriented to sustainability at the local level depends very much on the legal powers devolved to municipalities by provincial governments, on appropriate provincial policies and programs, and on effective cooperation between the two orders of government. In addition, sustainability policies may be frustrated by policies in other fields, such as public finance and transportation, that take little account of sustainability goals.

Furthermore, cities are profoundly affected by many federal and provincial policies and programs over which they have little influence, including those related to international trade, immigration and employment, national and provincial transport, regional development, and housing.

As well, local government in Canada still tends to be weakened by geographical and functional fragmentation. In many large cities, for example, the control of land use and transportation is shared not just by different municipalities (usually defined by arbitrary and ecologically irrelevant boundaries) but also by single-purpose regional or local agencies and by provincial government departments.

Problems arising from the "vertical" division of powers among the three orders of government are compounded by the "horizontal" division of functions within them. At each level of government there are many different departments and agencies, each of which has its own mandate, objectives, and priorities. However, efforts are being made to improve coordination and cooperation, both among the orders of government and among their departments and agencies.

In summary, urban sustainability involves the complex task of achieving an integration that balances social, economic, and environmental pluses and minuses; short- and long-term considerations; and the clear interests of a part of the population against the more diffuse interests of everyone. If the obstacles to be overcome in pursuing urban sustainability seem formidable, it is all the more heartening that progress is nevertheless being made, as the next section shows.

Making Canadian cities more sustainable

This section considers the most important areas in which policies and programs have been put forward, or called for, in the pursuit of urban sustainability. It also looks at what is actually being done in these areas — despite the difficulties that have been outlined — by all three levels of government.

Two points should be kept in mind. First, some policy and program ideas have not yet been fully tested in practice. Given the complex nature of the urban system, their consequences may not be entirely predictable or necessarily wholly supportive of sustainability. For example, although the present weight of opinion seems to be strongly in favour of urban "intensification" on social as well as environmental and economic grounds, it has been challenged in all three respects (Isin and Tomalty 1993; Simpson 1993; Campsie 1995). Indeed, the concept does involve some inherent contradictions: for instance, higher densities may militate against renewable energy use, on-site stormwater retention, or preservation of green space (Tomalty and Hendler 1994). Thus, a cautious pragmatism in applying new concepts is more prudent than a wholesale and uncritical embrace.

Second, the variety of Canadian cities and the range of actions being taken are too great to permit definitive conclusions based on rigorous statistical analysis. The information presented here is selected and generalized from several studies that differed in aims, coverage, and methodology. The major source used is a comprehensive survey by the Federation of Canadian Municipalities (FCM 1994, 1995), which attempted to secure information from all Canadian municipalities on their environmental actions (most FCM examples used here are derived from the 1994 report). A limitation of the FCM survey is that it includes rural municipalities as well as cities. Another key source is a review for the Intergovernmental Committee on Urban and Regional Research of environmental policies in a

sample of 15 municipalities, most but not all of them large cities (Ouellet 1993). The National Round Table on the Environment and the Economy has also developed a widely used resource book to assist local governments in moving towards a more sustainable community (Roseland 1992). This chapter therefore looks most closely at actions by municipalities and, to a lesser extent, by the two senior levels of government; a more complete review would include some noteworthy private initiatives as well.

The chief areas of policy and action towards urban sustainability are discussed under five headings: urban form, conservation, reduction of environmental impacts, transportation, and policy and governance.

Urban form

While a widely dispersed pattern of settlement would clearly have certain advantages for sustainability if it were possible, a more compact urban form is currently accepted as the key to more economical use of land, water, energy, and materials and to the reduction of urban dependence on the car. Aspects of this goal include:

- more intensive use, or "intensification," of land already urbanized (e.g., through redevelopment of abandoned or underused sites and conversion of obsolete industrial and commercial buildings to residential use);
- changing from the prevalent low-density suburban pattern to one that is denser and more compact;
- encouraging mixed-use development, together with a mix of different housing types and sizes, to reduce the need for travel;
- creating viable subcentres linked to one another and the city centre by high-capacity transit and mixed-use corridors; and
- the use of compact forms of housing and designs that provide ground-level access and some private outdoor space (D'Amour 1993). One example is the Grow Home, a narrow, two-storey row-house designed at McGill University's School of Architecture (Friedman 1994). Affordable and adaptable, it can be built at four times the density per hectare of the typical one-storey bungalow.

A number of urban municipalities across Canada — among them the City of Halifax, the Regional Municipality of Hamilton–Wentworth, Metropolitan Toronto, and the City of Regina — have prepared or revised their planning policies expressly to pursue the goal of a more compact urban form (Box 12.3).

Urban growth and structure

Provincial governments have taken different approaches to restraining the spread of their cities:

- consolidation (e.g., Winnipeg) or some form of metropolitan government (e.g., Toronto, Montreal, Vancouver) for the largest cities. In either case, however, the city tends to outgrow the new boundaries. Metropolitan or regional governments may also lack adequate political strength or legal powers for effective planning. Recently, broader and more integrated regional planning activities have been initiated, such as those by the Office of the Greater Toronto Area and the Task Force on Greater Montreal;
- a province-wide network of regional planning systems. These exist in Quebec and British Columbia and until recently existed in Alberta, although following different models;

Box 12.3
Urban form and environmental sustainability

Many of the courses of action needed to advance urban sustainability are directly related to the form of the city: the pattern and density of its physical fabric. The Canadian "sustainable city" of the future would ideally have the following characteristics:

- *a* ***substantially higher average density*** *than today's city, with land more fully used and single-family detached housing largely replaced by various more compact forms.*
- *a* ***network of subcentres*** *and the downtown area interconnected by mixed-use corridors and rapid transit. Each provides a range of services together with employment opportunities and moderate- to high-density housing.*
- *a* ***land use pattern*** *in which residential and other uses are mixed more than is usually the case now, with compatible, nonpolluting industries located in or adjacent to subcentres.*
- *a convenient, efficient, and reliable city-wide* ***transit system*** *and a network of safe* ***bicycle routes.*** *The use of private cars is restricted in favour of public transportation. Cars are excluded from certain parts of the city, such as the downtown area and the cores of the subcentres.*
- *a range of* ***housing choices*** *in every residential district, all built to high standards of energy and water efficiency. Residents can* ***walk safely and conveniently*** *to transit and cycle routes and to local schools, shops, and parks.*
- ***corridors of open space,*** *largely left in their natural condition, running through the entire city. These provide recreational opportunities and ecological links to parks and the open countryside.*
- *a well-defined* ***edge of the city*** *with no scattered urban infiltration into the surrounding rural area. Expansion is compact and carefully planned and mainly takes the form of physically separate "satellite" communities developed around their own subcentres and served by the city's rapid transit system.*

Such a reshaping of the city is attainable, would go far towards conserving land, natural ecosystems, energy, and water, and would greatly reduce air pollution. It would also provide an extremely liveable urban environment.

- provincial land use policies (Manitoba, Ontario) and special legislation to protect farmland (British Columbia, Quebec); and
- special agencies, such as Ontario's Niagara Escarpment Commission, which was created to safeguard a unique natural feature in Canada's most heavily urbanized region.

Some metropolitan and regional land use plans, such as those of the Greater Vancouver Regional District and Ottawa–Carleton, are aimed at creating suburban communities with a balance of housing and jobs in addition to community services and facilities. In Greater Toronto and Greater Vancouver, suburban "town centres" on high-capacity transit networks are being developed to house commercial and institutional activities once concentrated "downtown." Some municipalities, such as Winnipeg and Kitchener, have adopted urban growth boundaries.

Several new community developments on the edge of the city are currently being planned in such a way as to achieve explicit conservation and environmental protection goals as well as social goals. Examples are Bamberton near Victoria, McKenzie Towne on the edge of Calgary, and Cornell outside Toronto. All feature densities that are relatively high and encourage moving around on foot and by bicycle and transit rather than by car.

A comparison of a conventional suburban development with an alternative plan — involving a more compact form, a mixture of land uses, higher residential densities, narrower roads, and a modified grid street pattern to better accommodate transit — shows that urban development that supports environmental sustainability goals can also save money (Essiambre-Phillips-Desjardins Associates et al. 1995). The study for Canada Mortgage and Housing Corporation in association with Ottawa–Carleton showed that the costs over a 75-year period to build, operate, maintain, and replace the supporting infrastructure were 8.8% less per dwelling for the alternative plan than for the typical suburban development.

Table 12.7
Implementation of energy conservation initiatives by municipalities, 1994

Activity	Implementation			Total no. of municipalities responding
	Yes	Planned	No	
Energy efficiency standards for buildings	34	8	55	97
Retrofitting commercial buildings	5	5	60	70
Retrofitting residential buildings	7	3	58	68
Retrofitting municipal buildings	46	15	42	103
Retrofitting municipal streetlighting	69	5	33	107
Land use planning to promote energy efficiency (e.g., development patterns, housing intensification)	19	10	53	82
Increasing the proximity of housing to employment opportunities	7	7	54	68
Alternative fuels in transportation, heating, and cooling	12	4	60	76
Renewable energy sources (e.g., solar, wind, biogas)	5	2	64	71
District energy systems	1	2	65	68
Fuel conversion of municipal vehicle fleet	25	8	53	86
Fuel conversion of municipal transit fleet	5	3	61	69

Source: FCM (1994).

Within the cities, uniform single-use zoning is gradually being replaced by planning policies that selectively encourage a mixture of uses and dwelling types. Obsolete centrally located industrial and warehouse areas and rail yards are being renewed for different uses or replaced with housing, office buildings, and parkland, a process that typically involves some form of site cleanup. Examples include the Historic Properties in Halifax, Montreal's Vieux Port, Toronto's St. Lawrence neighbourhood, The Forks in Winnipeg, and False Creek in Vancouver.

Intensification

Intensification appears to have become a prominent policy issue in Canadian municipalities. A study carried out for Canada Mortgage and Housing Corporation concluded that "in *every* CMA [census metropolitan area] in Canada, the issue of developing or redeveloping land at higher densities has been addressed in at least one municipality. More importantly, *all* municipalities in [eight CMAs] declared intensification to be an issue" (Isin and Tomalty 1993).

These findings are generally supported by the other surveys. The FCM survey found a large number of policies and proposals related to intensification, covering zoning changes, building conversion, neighbourhood rehabilitation, infill, and redevelopment. Examples cited by the Ouellet study include the integration of places of employment and residence in mixed-use neighbourhoods in Vancouver, Toronto, Sudbury, Montreal, Dartmouth, and St. John's; promoting infill and redevelopment in Vancouver, Toronto, and Sudbury; and encouraging downtown housing construction in Toronto.

Other provincial and municipal initiatives that support higher-density communities involve new development and planning standards, as proposed in the Province of Ontario (1995); the promotion of smaller lots in new suburban areas; Main Street initiatives that encourage residential development above retail stores; and policies to allow apartments in single-family homes, such as in Ontario and some municipalities in British Columbia.

Conservation

Water conservation

The Ouellet study found 12 water conservation policies and programs in the 15 municipalities covered; the FCM study indicates that the most common municipal conservation measures are leak detection and repair, metering, public education, and use restrictions. A few cities have broader water management plans; these include Edmonton, the City of Toronto, Ottawa–Carleton, Laval, Cochrane (Ontario), and Rosemère (Quebec).

Energy conservation

With collective energy expenditures in the range of $1 billion, municipalities are focusing their efforts both on in-house energy management to reduce the fuel and electricity costs of the municipalities' own operations and on community-wide energy initiatives as a way of contributing to environmental, social, and economic objectives (Torrie Smith Associates, Inc. 1994). As well as providing direct financial gain, urban energy conservation is viewed as contributing to local economic development, improved air quality, reduced carbon dioxide emissions, and other environmental goals.

The FCM survey found a number of municipal initiatives for energy conservation, primarily in-house measures (Table 12.7). The most common were changing streetlighting, retrofitting municipal buildings, adopting energy efficiency standards for buildings, and converting municipal vehicles to alternative fuels.

Examples of urban energy conservation in Canada range from in-house energy savings by municipalities to comprehensive, community-wide energy management (Imola 1993; Maclaren 1993; Ouellet 1993; Torrie Smith Associates, Inc. 1994). Regina has one of the most advanced in-house energy management systems in the country, encompassing an energy efficiency office, an energy accounting system, independent funding, and an annual energy report. The accumulated savings of measures implemented as part of the City of Vancouver's in-house energy conservation program are now in excess of $1.5 million annually (Torrie Smith Associates, Inc. 1994). The city of Calgary has undertaken several energy conservation initiatives, including energy audits, energy reviews of the designs of new municipal facilities, energy controls in municipal buildings, and measures to conserve heating energy. The cities of Halifax, Montreal, Ottawa, Red Deer, and the Quebec Urban Community also have energy management programs.

Smaller communities are also saving energy. Espanola, an Ontario town of 5 400 people, with 2 300 "retrofitable" homes and businesses, is the site of a partnership with Ontario Hydro. The Espanola Power Savers Project tested a community-based approach to comprehensive energy demand management. Owing to very high adoption rates of energy management measures, the project is credited with annual savings of eight million kilowatt-hours and $600 000 in community electricity costs (Torrie Smith Associates, Inc. 1994).

Despite their potential, community-based district heating systems are relatively rare in Canada and make a rather small contribution to overall urban energy savings. A recent comparative study found that low usage of district heating was second only to modes of urban transportation in explaining the higher levels of energy consumption in North American cities compared with European cities (Torrie 1993). District heating currently provides space heating to buildings in the city cores of Toronto, Montreal, Vancouver, Winnipeg, and several other Canadian centres. European experience has shown that the more widespread application of district heating will require that it be integrated with the planning and development of both the urban infrastructure and the power supply system.

Energy conservation measures are also being adopted at the domestic level. Canada Mortgage and Housing Corporation, a number of provinces and utilities, and many municipalities are actively promoting energy efficiency in new commercial buildings, housing construction, and retrofitting. A 1993 study predicted that, depending on location, 90% of new houses would be 11–20% more efficient by 1995 than levels prescribed in the 1983 Measures for Energy Conservation, and the remaining 10% would meet the more stringent R-2000 standards (Natural Resources Canada 1993). A provincial law on energy efficiency in new buildings has been operational in Quebec since 1983.

Table 12.8

Access to and use of recycling programs by Canadian households, 1991 and 1994

	1991	1994
Total households (000s)	9 873	10 387
Access to recycling programs (%)		
Paper	52.6	69.6
Metal cans	48.9	67.2
Glass bottles	49.9	67.4
Plastics	42.1	62.8
Special disposal	26.4	40.2
Use of recycling programs by those who have access (%)		
Paper	85.8	83.1
Metal cans	86.2	83.5
Glass bottles	86.2	83.5
Plastics	84.7	81.7
Special disposal	51.7	57.1

Notes: 1. Special disposal includes paints, chemicals, batteries, etc.
2. Recycling programs include curbside recycling and recycling depots.

Source: Statistics Canada (1995a).

There seems to be ample opportunity for municipal governments to become more involved in urban energy management. Indeed, "true urban energy management for environmental improvement is still in its early stages in Canada" (Torrie Smith Associates, Inc. 1994). Municipal energy reduction initiatives are beginning to be linked to broader community environmental efforts. Examples include Ontario's Green Communities Program, which first focused on smaller centres such as Peterborough, Sarnia, and Guelph, and the establishment of 20% reduction targets for carbon dioxide by eight of Canada's largest urban areas.

Conservation of materials

The emphasis here is on the "3Rs": reduction of the volume of waste at source, reuse of materials, and recycling and composting of materials in the municipal waste stream.

The Ouellet study found that 4 of the 15 large urban areas covered (Vancouver, Toronto, Montreal, and Sherbrooke) have set firm targets for waste reduction. Toronto and Vancouver are attempting to improve controls on packaging, and Vancouver limits the amount of garbage the city will collect from each dwelling.

An estimated two million more households had access to recycling programs in 1994 than in 1991 (Statistics Canada 1995a). In 1994, 69.6% of Canadian households had access to the most widely available program, paper recycling, through either curbside recycling or recycling depots, compared with 52.6% in 1991 (Table 12.8). Access to recycling programs for glass bottles, metal cans, and plastics and to special disposal for household hazardous waste followed similar growth patterns. The increase in access to recycling varied by region and city size. Improved access was particularly evident in larger urban areas in Quebec and Atlantic Canada and in smaller centres in Ontario and western Canada, where the large cities generally had programs in place by 1991. Use of recycling programs by households that have access remained at more than 80% for the major materials, although it declined slightly over the three-year period, perhaps suggesting that recycling is less convenient in areas where programs have recently expanded.

Although composting of food and yard waste has strong potential for reducing the amount of organic material that enters the municipal waste stream, Canadian households have not accepted composting as readily as other recycling programs. In 1994, 23% of households reported use of a compost heap, compost container, or composter service, up from 17% three years earlier (Statistics Canada 1995a).

A sizeable proportion of Canadian municipalities now offer recycling programs, compost collection, and other waste reduction services (Statistics Canada 1995b). Of the 642 municipalities Statistics Canada surveyed for 1993, nearly three-quarters operated a recycling program, one-half had been involved in distributing backyard composters to residents, and one-third (serving 59% of the population) provided compost collection (Table 12.9). Waste composition studies and public education programs have also been undertaken by many municipalities. The percentage of municipalities offering various waste reduction programs varies directly with city size, likely reflecting the economies of scale that larger centres enjoy in establishing new programs. Changes in the size and scope of municipal recycling programs are indicative, to some extent, of recent improvements in the industrial market for recovered postconsumer materials and in consumer demand for end products that contain recycled material.

Table 12.9
Recycling and other municipal waste management programs, by municipality size, 1993

	% of municipalities reporting programs, by population size			
Programs	Canada (n = 642)[a]	Under 30 000 (n = 508)	30 000–99 999 (n = 97)	100 000 and over (n = 37)
Municipalities with recycling program	73 (16)	68 (23)	93 (16)	100 (13)
Compost collection	34	27	51	76
Distribution of backyard composters	50	46	62	76
Waste composition studies	27	24	35	46
Public education programs	56	50	76	89

Notes: 1. Figures are preliminary and do not include estimates for municipalities with populations of less than 5 000, which were not sampled.
2. Compost collection consists of pickup of yard waste during the spring and fall, as well as collection of Christmas trees in January.
3. Figures in parentheses represent waste recycled as a percentage of total waste collected.

[a] n = number of municipalities reporting.

Source: Cameron (1995); Statistics Canada (1995b).

Conservation of ecosystems and natural features

The responses to the FCM survey show a relatively high degree of commitment to conserving natural areas, environmentally sensitive areas, and natural habitat: "many municipalities have policies for conserving green space, environmentally sensitive areas, parks and conservation areas and . . . the majority of these are being implemented. Wetlands, shore zones, urban forests, and wildlife corridors also receive consideration in policy and implementation" (FCM 1994). However, the extent and effect of the implementation of such policies need further investigation.

Among 15 municipalities studied, Ouellet found 9 policies or programs relating to agricultural land, 14 on environmentally sensitive areas (of which 5 were being implemented), 12 on greenway systems (7 being implemented), 4 on biodiversity, and

2 on the ecosystem approach to planning. Nevertheless, "the protection of biodiversity is still in its infancy at the local level. In many municipalities, the protection of habitats is just beginning through the designation of environmentally sensitive areas or has yet to be initiated" (Ouellet 1993).

Cities are moving away from the traditional perception of urban parks exclusively as "green islands" intended for various forms of recreation. Montreal, Toronto, Edmonton, Ottawa, and other cities are attempting to create or restore systems of green corridors through the urban fabric, making use of residual natural areas, cemeteries, waterfronts, institutional lands, transmission line rights-of-way, and other open spaces. These linked systems are intended in part to encourage the restoration of wildlife populations and natural ecosystems. Also, cities are now undertaking "urban forestry" and breaking away from traditional park management practices by encouraging naturalization and substitution of integrated pest management for chemical pesticides (City of Toronto 1993). Experimentation with the use of herbivorous animals to replace gasoline-powered lawnmowers has occurred in such far-flung places as Gander, Newfoundland, and Fort Saskatchewan, Alberta (FCM 1995).

Cities and provincial governments are in many cases giving special attention to the restoration of urban stream valleys and waterfronts. Among the notable examples are False Creek in Vancouver, the valley of the South Saskatchewan River in Edmonton, The Forks in Winnipeg, the City of Toronto's Task Force to Bring Back the Don, the Rouge Valley Park in eastern Metropolitan Toronto, and the "heritage river" designation for the Grand River, which flows through several Ontario cities.

The concept of "ecosystem-based planning" became well known through the publications of the Crombie Commission (Royal Commission on the Future of the Toronto Waterfront 1990, 1991; Doering et al. 1991) (Box 12.4). Essentially, it means land use planning that is based on natural boundaries and respects the integrity of ecosystems (Tomalty et al. 1994). The "larger objective" of recent municipal planning legislation in Ontario is stated to be "to create an ecosystem planning process" (Ontario Ministry of Municipal Affairs 1994). It has become commonplace to include ecosystem planning as a principle in new and revised municipal land use plans, although, according to the Ouellet study, "There are only allusions to the ecosystem approach to planning in many of the municipal plans studied. In general, the concept and implementation of an ecosystem approach to planning is relatively new and it will take some time to see its integration into municipal planning" (Ouellet 1993).

Nevertheless, a comprehensive review of the official plan of Ottawa–Carleton is explicitly based on the principle that the regional municipality is part of the ecosystem. Other examples of planning with an ecosystem approach in Canadian cities include the Fraser River Estuary Management Program and Fraser Basin Management Board in Greater Vancouver, Saskatoon's Meewasin Valley Authority, the Laurel Creek Watershed Study in the City of Waterloo, the Greater Toronto Area's Waterfront Regeneration Trust, and the Hamilton Harbour Remedial Action Plan (Tomalty et al. 1994). The ecosystem approach and the ecological role of natural areas were specifically recognized in the creation and identification of Greater Vancouver's "Green Zone" (GVRD 1992, 1993c). All of these examples involve some form of special institutional structure extending beyond the municipal level of government.

Reduction of environmental impacts

It is widely accepted that, as far as possible, the city should be free of activities that are potentially harmful to the health of either people or natural ecosystems, within or beyond its own limits. Yet progress towards reducing environmental impacts faces a range of fiscal, jurisdictional, and behavioural obstacles.

Air quality

The chief means of lowering concentrations of ground-level ozone is reducing the emissions of its precursors (nitrogen oxides and VOCs) by motor vehicles.

Air pollution control is largely in the hands of the federal and provincial gov-

Box 12.4
Towards an ecosystem approach to land use planning

How . . . does the ecosystem concept affect planning activities? It suggests many alternatives to traditional ways of doing things. For example, an ecosystem approach should:

- *encompass natural, physical, social, cultural, and economic considerations, and the relationships among them;*
- *focus on understanding interactions among air, land, water, and living organisms, including humans;*
- *emphasize the dynamic nature of ecosystems;*
- *recognize the importance of living species other than humans, and of future generations; and*
- *work to restore and maintain the integrity, quality, and health of the ecosystem.*

A key to understanding ecosystems is therefore to recognize that "everything is connected to everything else" — one reason why cumulative effects occur as a consequence of many actions in an ecosystem. . . .

Another important point to note is that, because ecosystems include humans, their needs and activities — the matters we think of as community and economic concerns — are just as much a part of the ecosystem as the natural and physical environments.

Source: Excerpt from Barrett and Davies (1991).

ernments. Action at these levels, such as the banning of leaded gasoline and the regulation of automobile emissions under the federal *Motor Vehicle Safety Act* and the regulation of other emissions under provincial legislation, has been responsible for the generally hopeful picture presented by the national air quality data.

The federal and provincial governments have taken action to:

- maintain and strengthen the NAAQOs and other existing air quality standards and regulations;
- keep the NAAQOs and other standards (including the definition of "acceptable level") under continuous review; and
- investigate further the potential effects of air toxics and of combinations of pollutants.

These controls probably also account for the fact that, according to the FCM survey, most municipalities do not appear to find air quality a serious problem. However, this depends very much on the location, size, economic base, and other circumstances of the individual municipality. Some cities are themselves taking action to improve air quality and also to reduce emissions that contribute to global climate change ("greenhouse gases") and stratospheric ozone depletion. Eight cities — Victoria, Vancouver, Edmonton, Regina, Metro Toronto and the City of Toronto, Montreal, and Ottawa — have joined the "Twenty Percent Club," each with its own plan to reduce greenhouse gas emissions by 20% from their 1988 levels by the year 2005.

Several municipalities have policies and programs relating to the purchase of ozone-depleting chemicals and to the reduction of emissions of sulphur dioxide, carbon dioxide, and nitrogen dioxide, and programs are being implemented to make use of alternative fuels (Ouellet 1993). For example, the Vancouver City Council has adopted all 33 recommendations made in 1990 by its Task Force on Atmospheric Change to improve air quality and to reduce "greenhouse gas" and ozone-depleting emissions (City of Vancouver Task Force on Atmospheric Change 1990; Maclaren 1993). The Greater Vancouver Regional District has prepared a draft Air Quality Management Plan in conjunction with its regional land use action plan (GVRD 1994). The City of Montreal has developed a Strategy for Reducing Emissions and the Use of CFCs and Halons (also regulated throughout the province of Quebec as of July 1993), whereas the City of Toronto has set specific targets for reducing sulphur dioxide emissions by 2006 (Ouellet 1993).

Water quality

Ideally, there should be no increase in the net level of impurities in the hydrologic cycle. Water discharged to the receiving waters should be at least as clean as when it enters the supply system or falls as natural precipitation. Many jurisdictions have concluded that this implies:

- secondary or tertiary treatment (depending on the characteristics of the receiving waters) of all wastewater, including storm drainage;
- measures to prevent overloading of treatment plants in heavy storms; and
- improvements to the collection system, if needed, to prevent leakages resulting from age and deterioration.

As described above, the level of wastewater treatment in Canada has generally been rising, although it varies considerably across the country (see Fig. 12.14). Among the large cities, the Montreal Urban Community has recently completed a major sewage treatment scheme (BSQ 1995). Some smaller cities, such as Banff and Portage La Prairie, are experimenting with innovative methods of sewage treatment (FCM 1995). For instance, there is increasing interest in the possibilities of forms of treatment that rely on biological processes (French 1994).

However, some coastal cities discharge their sewage into the sea untreated or after only a low level of treatment, arguing that if the depth of the discharge and its distance from the shore are adequate and the currents suitable, health risks and harm to the environment are negligible. This is a matter of dispute: Victoria's discharge of untreated sewage into the Strait of Juan de Fuca, for example, is a source of continuing complaints from the State of Washington.

Waste management

A good waste management program helps protect the environment and conserves materials, as it reduces the total quantity of waste that the environment must assimilate. However, any disposal method will have some adverse environmental effects. These may be reduced, but they almost certainly cannot be entirely eliminated. In addition to promoting the "3Rs," many cities are:

- locating landfills to minimize truck traffic;
- locating, designing, and constructing landfills to prevent leaching and gas emissions, ultimately to enable them to be restored as usable land;
- employing the best available technology in incinerators, if used; and
- involving the public in the planning of disposal programs.

Cleaning up

Cleaning up the harmful environmental legacy of a city's past may entail:

- within the city, dealing with contaminated land by removing the soil (which then must be treated somehow or harmlessly disposed of) or by finding ways of using such sites without putting personal health at risk; and
- outside the city, dealing with old disposal sites, such as garbage and tire dumps, which may affect groundwater or pose health or fire hazards.

Although the FCM survey revealed a low level of action regarding contaminated land, many of the municipalities responding would have only minor problems of this nature, if any. The Ouellet study of 15 large municipalities found a total of 10 policies and programs related to site rehabilitation, of which 5 were being implemented. The cities of Vancouver, Calgary, Toronto, Ottawa, and Montreal

all have comprehensive inventories of contaminated sites and development review processes.

Transportation
Transportation is a key action area, because the implications of transportation decisions affect the urban environment in so many ways. Apart from walking and human-powered vehicles, such as bicycles, all forms of transport entail significant consumption of resources and impacts on the environment, especially on air quality.

Ways of achieving more sustainable urban transportation include:

- shifting budgetary and program priorities from road systems to transit systems;
- providing more diverse transportation options, such as rapid transit, commuter rail, and surface transit networks, special facilities for high-occupancy vehicles (e.g., car pools, van pools), and cycle and pedestrian ways;
- improving the efficiency, speed, reliability, and general attractiveness of transit by such means as dedicated lanes for buses, transit priority at intersections, schedule reliability, provision of up-to-the-minute travel information, and integration of fares and schedules between routes and systems;
- encouraging more efficient use of infrastructure and vehicles (e.g., travelling at off-peak times, combining trips, substituting transit for car use, sharing vehicles, and using less congested routes);
- discouraging unnecessary automobile use in local residential areas by such means as "traffic calming" street design;
- providing public outreach, awareness, and education programs;
- improving vehicle technology by designing lighter, more aerodynamic vehicles and smaller, more fuel-efficient engines, and by developing alternative fuels; and
- reducing the need for vehicular movement. This could be achieved through an urban design in which land use and transportation planning are effectively integrated, creating pedestrian-friendly streets and compact centres of intensive mixed activity linked by mixed-use corridors (Box 12.5).

Box 12.5
New visions in urban transportation: specific strategies and actions for implementation — urban structure and land use

Delegates discussed various ways to implement plans for increased densities and more mixed land use to reduce travel distances and support walking, cycling and transit. The following common strategies received general support:

- *The public should be engaged in a debate about life choices and urban structure, highlighting both the sense of urgency for action and the social and economic benefits associated with a new urban vision.*
- *Within municipalities communities must be supported in efforts to define their needs.*
- *Mixed uses should be designed to meet locally-defined needs, at the lowest cost possible.*
- *New land use patterns should be both economically and environmentally sustainable.*
- *Urban structures should encourage a shift to transit (through more compact and dense urban forms).*
- *The political leadership should visibly support a new urban vision and involve the public in shaping its implementation.*
- *The planning and delivery of land use and transportation policies should be better integrated, and should involve all orders of government working in a more cooperative manner.*
- *People should be provided with appropriate financial incentives by having taxes and user charges reflect the costs of municipal services (e.g., unit cost assessment, vs. market value assessments).*
- *Appropriate incentives should be provided to developing mixed land use communities (better balance of jobs/residences; diversity of housing types; better mix of housing, services and retail).*
- *Incentives should also be provided for in-fill development, especially along transit routes.*
- *Laws/regulations should be reviewed and . . . brought into line with a new vision for urban structure and land use.*

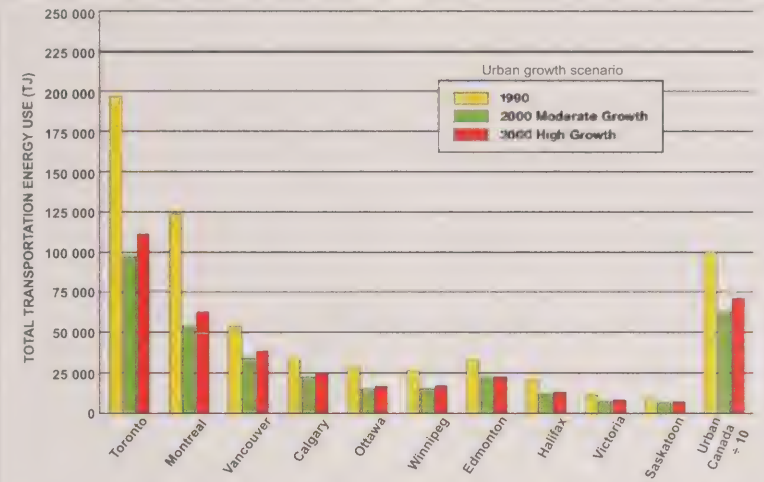
Source: Excerpt from Transportation Association of Canada et al. (1994).

A 1993 study of transportation energy consumption in 10 Canadian cities, including the largest 7, suggests that application of these measures, even without changes in urban structure or improved emission control and fuel efficiency, could reduce average energy use by 29–36% (depending on assumptions about growth in travel) between the years 1990 and 2000 (Fig. 12.22).

A paper prepared for a 1994 symposium on "New Visions in Urban Transportation" (Irwin 1994) cites a variety of actions being taken or planned across Canada, especially in the "Big Three" cities (Toronto, Montreal, and Vancouver), but also in other large centres. The initiatives are outlined under the headings of urban structure and urban design policies, transportation infrastructure, demand management, traffic and transit management, and cleaner vehicle technology.

The findings of the Ouellet study are similar: a number of municipal policies and programs are planned or under way to improve transit, to encourage cycling, and to reduce car use through parking-related measures. Specifically mentioned are transit service improvements in Toronto, Montreal, St. John's, and Dartmouth and reserved bus lanes in Vancouver, Toronto, Ottawa, and Montreal. Parking-related

Figure 12.22
Transportation energy use: potential year 2000 results if all initiatives are implemented



Note: Urban Canada represents all Canadian urban areas. The totals for urban Canada have been divided by 10 to fit the scale of the graph. The data for urban Canada are population-weighted estimates. Those urban areas not individually listed are assumed to have characteristics similar to those of the three smallest urban areas shown. Calculations are based on Kent Marketing Limited fuel sales data for Canadian urban areas.

Source: IBI Group (1993b).

measures have been proposed in Toronto, Montreal, and Vancouver. Bicycle networks are being created in six metropolitan areas and considered in others; pedestrian networks exist or are being created in seven.

Policy and governance

"An ecological city is distinguished by the degree to which environmental considerations are incorporated into decision-making in public and private sectors alike" (OECD 1993).

To move deliberately and consistently on a course of urban sustainability implies a more holistic, ecosystem-based approach to urban policy and governance than has been usual in Canada, the kind of approach that the Crombie Commission indicated for the Greater Toronto bioregion (defined on the basis of natural rather than political boundaries; Royal Commission on the Future of the Toronto Waterfront 1991). More specifically, it would entail:

- developing and implementing urban sustainability goals, standards, and criteria;
- monitoring progress, including the determination of appropriate benchmarks and indicators and state of the environment reporting;
- fiscal policies supportive of sustainability goals (e.g., recognizing the connections between property taxation and land use);
- economic development policies consistent with sustainability goals and principles; and
- integrated, effective planning for the entire urban region.

Of these, only the first two are under the control of local governments as well as of the other orders of government; the remainder are dependent on the policies and actions of provincial governments and to some extent those of the federal government too. Nevertheless, municipal governments have made appreciable progress in reorienting policy- and decision-making towards sustainability.

Overcoming municipal fragmentation

Canada was a pioneer in the creation of forms of municipal federation, or at least coordination, at the regional or metropolitan levels. There are several examples of local governments working together to plan for sustainability. These include the Greater Vancouver Regional District's Liveable Region Strategy, a comprehensive review of the official plan of the Regional Municipality of Ottawa–Carleton, and the Regional Municipality of Sudbury's land reclamation program. In some cases, cooperative planning extends beyond regional or metropolitan boundaries or beyond the municipal level of government, or both. Examples include the Fraser River Estuary Management Program and the Hamilton Harbour Remedial Action Plan, in which municipal governments are collaborating with provincial and federal departments and other agencies.

Sustainability policy

As well as initiatives in particular fields, the FCM survey found that some municipalities are adopting more comprehensive sustainable development or environmental policies. These municipalities now face the challenge of implementation. For instance, a report by the Round Table on the Environment and the Economy of the City of Halifax elicited a 47-page response from the city, detailing specific actions to address the report's recommendations. The Regional Municipality of Hamilton–Wentworth has adopted a vision based on principles of sustainable development as the basis for its decision-making over the next 30 years (Regional Municipality of Hamilton–Wentworth 1993; Pearce 1995).

Organizational change

Many municipalities have made organizational changes to achieve environmental objectives. As of late 1994, roughly 30% of the municipalities responding to the FCM survey had a municipal council environmental committee or task force, and 16% had an interdepartmental environmental committee made up of municipal staff. Other changes included creating staff positions with special environmental

responsibilities, establishing an environmental office, or giving a particular department the responsibility for coordinating environmental activities. A countervailing trend, however, is the recent and impending reductions in environmental programs in some municipalities as a result of severe budgetary cutbacks.

Sustainable development and state of the environment reporting

Several national studies have concluded that there are relatively few municipal state of the environment reporting initiatives in Canada (Burch 1994; FCM 1994). A more recent survey found that state of the environment reports were completed, in preparation, or under consideration in 20 of the 40 municipalities that responded (Campbell and Maclaren 1995). Others were preparing or had completed reports on quality of life, state of the city, or environmental issues. The authors concluded that municipalities need more usable data from the provincial and federal governments, guidance on reporting methods, and better environmental indicators.

Environmental assessment

In the municipalities studied by Ouellet, environmental assessment is intended mainly to protect environmentally sensitive areas. The City of Ottawa has, however, introduced a more comprehensive "Municipal Environmental Evaluation Process," and other municipalities are following suit. It can be expected that some form of environmental evaluation will increasingly form part of the municipal review of development applications, although its effectiveness may be limited both by constraints on the powers of the municipality and by a lack of appropriately qualified staff (Richardson 1994a).

Citizen action

Municipalities are making an effort to involve residents in environmental actions, ranging from community cleanups to bird counts (Fig. 12.23). The programs help to get the general public involved in improving the local environment and also serve as a form of education. The persistent and often well-informed and skilful lobbying of environmental advocacy organizations has in many cases helped to bring about new or improved policies and even new agencies and programs within the city.

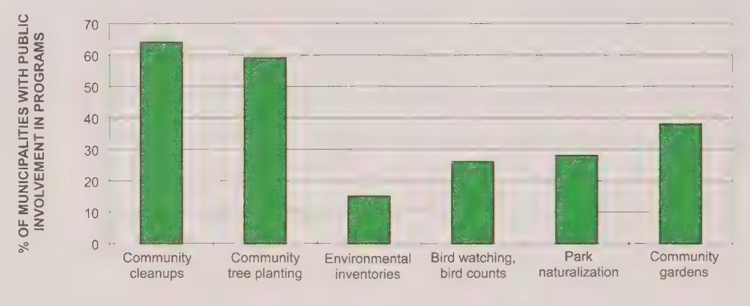
Local round tables on the environment and economy, modelled on the national and provincial round tables, bring together representatives of different interests in the name of sustainable community development. The achievement of the Halifax Round Table has already been mentioned. The similar aim of the "healthy communities" movement is to work with municipal governments towards the common goal of socially, economically, and environmentally healthy communities. Quebec, British Columbia, and Ontario all have active healthy community networks supported by the provincial governments.

According to the former Executive Director of the National Round Table on the Environment and the Economy, "Hundreds of communities have now developed comprehensive sustainable development strategies through local round tables . . . or through other citizen-led, multi-stakeholder processes. They all contain achievable and practical short-term targets in the context of a strategy for medium and long-term change" (Doering 1994).

Conclusion: Is Canada Moving Towards Urban Sustainability?

On balance, are Canadian cities being planned and managed in a way that is moving them towards greater sustainability? Are they reducing their resource demands and lessening stresses on both local ecosystems and the global ecosphere?

Figure 12.23
Involvement of the public in environmental actions by municipalities, 1994



Source: FCM (1994).

Box 12.6
The future of urban planning: towards environmental sustainability

Urban environmental planning involves a complete reconceptualization about the function of the built environment and the role of technological infrastructure. The task faced by future environmental planners is developing human habitat alternatives that are ecologically, economically, socially and technologically viable as well as culturally appropriate and aesthetic.

Source: Excerpt from Tyler (1994).

A definitive answer is not yet possible, if only because of the lack of a body of complete, consistent, and comparable information. Nevertheless, some general conclusions can be reached.

In the basic "housekeeping" categories of air and water quality and waste management, subject to various reservations and exceptions, progress is being made. This is also true with respect to the conservation of water, energy, and materials, although to a lesser extent: more can be done in these areas. Canadian municipalities are making substantial efforts in the conservation and protection of environmentally sensitive areas, green space, and natural systems. Intensification has become a major policy goal, and restraints on low-density expansion in the urban fringe are gradually tightening. Cities are making varied efforts to get their citizens to use transit, bicycles, and their feet instead of their cars. New approaches and techniques, such as sustainable development policies, environmental assessment, and state of the environment reporting, are beginning to make their appearance on the munici-pal scene.

Based on a study of Canada's 23 largest municipalities, one analyst found that "the local response to achieving sustainable development is producing some profound changes in the way that municipal governments operate and the types of issues they are being asked to deal with" (Maclaren 1993). Elsewhere, the same writer asks: "Are we making any progress toward achieving that goal [of planning for sustainable urban development]? I think the answer to that question is an undeniable 'Yes' " (Maclaren 1994).

This is a generally encouraging picture. Beyond it, unfortunately, dark clouds remain on the horizon.

Further progress in the conservation of energy and land and the improvement of air quality depends on attaining two connected objectives: a more compact urban form and a substantial shift in modes of transportation. These objectives are, in fact, the key to urban sustainability in Canada (Box 12.6).

Although municipal and provincial governments are taking action in these areas, it is by no means certain that enough is being achieved or can be achieved. Intensification presents many practical difficulties and will at best help to limit fringe growth. Substantial improvements to transit are costly, and transit expenditures are currently being cut back in many cities in light of government fiscal restraint. Considered in the context of current market forces and consumer preferences, it seems very unlikely that large numbers of people will change their loyalty from single-family houses to more compact types of housing or from cars to buses or subway trains, at least within the foreseeable future. The demographic trends are not encouraging, especially the implications of an aging population. Yet Canadian cities continue to grow, and the number of cars continues to rise.

Looming in the background of this already uncertain scene is the prospect of climate change. The possible implications of global warming include flooding for some cities and depletion or degradation of the water supply for others; increased energy demands and deteriorating air quality; and even serious consequences for the economic base in some centres. The city is made more vulnerable to these long-term threats by its heavy and growing dependence on a "global hinterland," where resources are being depleted or themselves made more vulnerable by reduction of biodiversity.

Under all these circumstances, is it possible for Canadian cities to move solidly towards urban sustainability, or at least to avoid losing ground? Although they have begun to change course, how much real progress they will be able to make, and how rapidly, must still be considered an open question.

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THE STATE

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CANADA'S

ENVIRONMENT

1996

PART IV

CANADA IN THE GLOBAL CONTEXT

Introduction

In Part III, the scale of the report changed from regional to national. In the three chapters of Part IV, the geographical frame extends again, this time to encompass the whole of planet Earth. The description and analysis continue to focus on Canada, but the chapters deal with topics — atmospheric change (global warming and stratospheric ozone depletion), diminishing biodiversity, and the effects of toxic substances on ecosystems and human health — that represent major threats to environments and ways of life, not merely in Canada but worldwide. Each of them, to borrow the phrase used in Chapter 15, has "the potential to jeopardize the Earth's life support system."

These topics have a much more localized relevance as well and are referred to frequently in Parts II and III of this report. Sometimes a Canadian ecozone is a significant contributor to the global problem; other times it may suffer from events and sources originating far away. In many areas, both types of interaction are evident. Understanding the situation in Canada with regard to these issues, however, demands an understanding of their global dimension.

There is no mystery about why some environmental issues are global in scope. The Earth is characterized by motion, involving both natural and human forces. Nearly 71% of the planet is covered by oceans, and all of it is enveloped by an even more dynamic fluid — the atmosphere. Winds carry energy, particles, and pollutants around the world in a matter of days. Ocean currents do the same, but over a longer time scale. Aircraft and ships, while moving freight and passengers to every corner of the globe, may also carry species and pathogens from one ecosystem to another. Although border inspections, vaccinations, and quarantines may limit the transmission of disease, no exclusively national solutions exist to deal with the problems discussed in the following three chapters. Effective action in most cases requires changes in patterns of behaviour or lifestyles that may need to be extended throughout the world through international collaboration. At present, each of the issues represents a "clear and present danger" for which responses and countermeasures are, at best, in only an early stage of development.

Although the issues discussed in the following chapters appear extremely diverse, they have at least four important characteristics in common:

1. *They are global in scope.* This means much more than the fact that mercury in a Japanese harbour, for example, can have the same effect on ecosystems and human health as mercury in Canadian waters. It also means that, because of the efficient exchange mechanisms between water, air, and other environmental components, toxic substances can be transported thousands of kilometres and have effects far beyond their place of origin. Further, the global character of these issues means that they can be tackled effectively only if governments and populations throughout the world take effective and coordinated action.

2. *There may be a substantial time lag between "cause" and "effect."* The health effects of chronic toxic contamination may not appear until years after exposure begins or may even be delayed until the next generation. The chain of events that causes species to become extinct may extend almost unnoticed over many years. Because of such time lags, the recognition of problems is often delayed and the identification of causes is difficult. Although the human contribution to atmospheric pollution has been apparent since the industrial revolution and has been substantial on a global scale for half a century, incontrovertible evidence of global warming is not yet evident in the climate record. Chlorofluorocarbons (CFCs) have been available in various forms for a century, but their role in depleting stratospheric ozone was not demonstrated until the 1980s.

3. *The consequences are long lasting and sometimes irreversible.* Irreversibility is most obvious in the case of species extinction: once gone, a species is lost forever. Chapter 14 suggests that "as many as two-thirds of all species now living may face extinction within the next century." In theory, global warming may be reversible; in reality, however, as "sinks" of carbon dioxide, such as the world's oceans, cannot keep pace with the growing output of carbon dioxide from anthropogenic sources, "steady-state" balances may require thousands of years to achieve. Toxic substances in the environment may remain a threat on time scales from a few months to the indefinite future (half a century or more for the pesticide dichlorodiphenytrichloroethane [DDT] and its decay products; tens of thousands of years for radiation from uranium mine tailings). Even the relatively swift action taken in recent years by the world community to reverse stratospheric ozone depletion will bring only modest improvement in the short term. CFCs and halons will be phased out by the end of the century by most of the major users, but exposure to ultraviolet-B radiation from the sun will continue at recent levels for another two decades, and it may take a century for ozone concentrations in the stratosphere to be restored to pre-CFC levels.

4. *The source of these problems is to be found mainly in human preferences and actions.* Species are lost because tropical forests are cleared to provide timber, firewood, and arable land for expanding populations or perhaps to meet a temporary export demand that could be met from other sources. Chemicals are mass produced because people want the convenient and affordable products they make possible. Petroleum

is extracted and consumed in vast quantities because of the mobility it confers. CFC production was expanded because air conditioners and spray cans seemed to improve the quality of life. But all of these benefits have come at a price that is only now being recognized. Toxic chemicals persist long after the products they were part of have been discarded. The combustion of petroleum contributes to local air pollution and global warming, and CFCs cause dangerous depletion of stratospheric ozone.

Each of these issues is also affected by scale: the problems can magnify rapidly and outpace the ability of the world community to respond adequately. Given the large scale of modern technology and its global extent, the occasional and inevitable accident is liable to have widespread effects. Such was the case when design faults together with unauthorized procedures caused the Chernobyl nuclear disaster, the effects of which were felt thousands of kilometres from the site.

Because everyone everywhere is affected, and because the consequences may be irreversible and, in some cases, may include substantial human health effects, the arguments for urgent global action on these issues would seem to be irresistible. All too easily, however, the arguments become submerged by competing pressures and priorities. Part of the explanation for this may be simply human nature: an effect expected at some indefinite date in the future seems much more remote and less compelling than more immediate pressures, such as those of the economy, that affect our well-being now. Wise or wasteful use of petroleum and other fossil fuels, for example, is still shaped more by price than by concerns over global warming.

Probably of much more significance, however, is the human tendency to evaluate issues in terms of how they affect us as individuals. Although people may care about the environment in a general sense, the extinction of a single species may not have an immediate or direct effect on the circumstances of their lives. From the media coverage, they may feel that the ozone depletion problem is being dealt with adequately. Similarly, global warming seems too complex a problem for most individuals at present, and scientists are not all in agreement about how quickly it could occur or what its specific consequences might be. People are left with an overall sense that these issues are remote, that there is nothing that they personally can do that is going to affect greenhouse gas levels or other global-scale problems in any meaningful way.

Because it is natural for people to be most concerned about what affects them directly, locally, and immediately, it is more difficult to develop concern for events in the future or in other places. Environmental priorities of this kind may not appear comparable to other priorities, in terms of the need for urgent action, allocation of financial resources, or changes in lifestyle.

Indeed, experience in recent years seems to suggest that action or inaction on these global issues is only loosely related to the actual threats they pose. If ranked according to the amount of coordinated and effective international action they have so far received, these issues would line up as follows: (1) protection of stratospheric ozone; (2) control of toxic substances entering the environment; (3) maintenance of biodiversity; and (4) limiting emissions of greenhouse gases.

The reasons why protection of stratospheric ozone tops this list are fairly clear. The principal chemicals responsible for reducing ozone concentrations are few in number, and most of them have been produced by a small number of major chemical corporations in a small number of industrial countries. More important, substitutes for these chemicals are available that are feasible on both technical and economic grounds. As Chapter 15 shows, these substitutes are not entirely risk free in environmental terms, but they do represent at least an interim solution to the ozone depletion problem. A further advantage is that most of the adjustments necessary to introduce these substitutes can be achieved with minimal inconvenience to the individual citizen. For example, new refrigerators and new air conditioning units automatically come with CFC substitutes installed. Like the introduction of unleaded gasoline, therefore, the adoption of ozone-friendly chemicals does not involve major changes to individual lifestyles, nor does it require specific action by the majority of the population.

Contrast this situation with the problems that confront actions to limit the emission of greenhouse gases. Canadians already use large amounts of fossil fuels on a per capita basis and tend to resent price or other restrictions on fuel use. Meanwhile, at the global level, energy is regarded as vital to advances in living standards in developing countries. India and China, for example, have vast resources of coal and envisage huge increases in the use of fossil fuels during the coming decades. Reducing emissions in both developed and developing countries thus involves difficult choices, and few of them, either for governments or for individuals, can be popular and effective at the same time.

Protecting species and ecosystems from extinction may also conflict with short-term attempts to improve living standards. On the positive side, as Chapter 14 records, the Framework Convention on Biological Diversity has been signed and ratified by the majority of the nations of the world. But it is a framework convention that at the moment relies mainly on national action to identify and protect species, genetic material, and ecosystems. In the humid tropics, in particular, large numbers of species depend for their survival on the protection of areas and ecosystems that, from another standpoint, may represent opportunities for short-term economic development. Even in Canada, recent events have shown that different people place very different values on the plant and animal species that flourish only in the "old-growth" forests that have so far escaped logging.

The situation with regard to toxic substances also seems uncertain. As a leading industrialized country that develops and produces an ever-increasing arsenal of new chemicals, Canada has a special responsibility to ensure that all chemicals are handled responsibly at every stage of their life cycle, from development and production to

distribution, use, and final disposal. One of the main instruments for discharging that responsibility is the Great Lakes Water Quality Agreement with the United States, which has as its principal objectives the "zero discharge" and "virtual elimination" of persistent toxic chemicals in the Great Lakes ecosystem. Both countries have committed substantial resources to these objectives since the present Agreement was signed in 1978. Yet, as the International Joint Commission observed in 1992 and reiterated in 1994: " 'we have not yet virtually eliminated nor achieved zero discharge of any persistent toxic substance' from the waters of the Great Lakes Basin Ecosystem. Indeed, we have not even come close to elimination" (International Joint Commission 1994).

The three chapters in Part IV offer readers the opportunity to assess how well the world community is responding to the environmental threats described in them and to make a similar assessment of the adequacy of the Canadian contribution to the global effort. In the latter context, it may be worth recalling the comment of a Dutch witness before a House of Commons committee in January 1990. He had described the strong measures approved by the Dutch Parliament to reduce greenhouse gas emissions in that country. When the Committee noted that the Netherlands accounted for a much smaller proportion of global carbon dioxide emissions than Canada (0.6% of industrial carbon dioxide emissions in 1989 versus 2.1% for Canada; numbers calculated from World Resources Institute 1992, Table 24.1), he replied: "This is simply a matter of where all the individual small contributions add up. There is simply no way one country or a small group of countries can solve this problem. We are all into it, and we all have to make our own contribution" (House of Commons Standing Committee on Environment 1991).

In assessing where Canada stands in relation to both the creation and the solution of the global problems discussed in the next three chapters, these words are worth bearing in mind: "We are all into it, and we all have to make our own contribution."

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Chapter 13 Toxic Substances

Highlights

There is growing concern over continued low-level exposure of ecosystems and people to a range of trace metal contaminants and both short-lived and persistent organic pollutants. Nonlethal effects include disruption of the endocrine system and associated consequences, including reproductive and immune system dysfunction, neurobehavioural and developmental disorders, and possibly certain forms of cancer. Embryonic exposure leading to transgenerational transfer of effects is a particular concern.

■

In the Great Lakes ecosystem, ambient levels of contaminants, which initially fell sharply as pollutant releases were reduced, are no longer decreasing, despite continuing reduction in industrial and municipal point source discharges. This "plateau" effect may reflect an ecosystem response that can be expected in other regions as they also bring down pollution levels.

■

Cold northern regions, such as Canada's Arctic, act as a sink for contaminants subject to long-range transport. The implications for both ecosystem and human well-being are important and add a sense of urgency to the need for continuing research, information dissemination, and the pursuit of a sound global regime for management of persistent toxic substances.

■

An agreed-upon management and long-term disposal strategy for radioactive substances does not exist in Canada. This is true for both high-level radioactive waste from nuclear reactors and low-level radioactive waste from uranium refineries, nuclear facilities, hospitals, research institutes, and uranium mines. However, a concept for the disposal of nuclear fuel waste deep in the Canadian Shield is currently under review.

■

Approaches to the management of toxic substances are evolving rapidly. Sophisticated full-system approaches to industrial processes are replacing simple "end-of-pipe" techniques. A life cycle management or "cradle-to-grave" approach is emerging, supported by full-cost accounting techniques and rigorous systems of site assessment and environmental auditing. These approaches represent the emergence of a new concept of industrial ecology, and an overall pollution prevention strategy incorporating these ideas is now a central theme in federal government policy. Drafting of international standards for environmental management systems through the International Organization for Standardization's ISO 14000 program is nearing completion. These developments signal a shift towards pollution prevention on a broad scale.

■

Systematic monitoring of toxic substance releases is just beginning in Canada. The National Pollutant Release Inventory and the monitoring aspects of the Accelerated Reduction/Elimination of Toxics program show promise, but their effectiveness remains to be established. There are serious limitations to other sources of data and information on toxic substances as well, both in Canada and worldwide.

■

The relevance of biotechnology to the toxic substances issue includes two dimensions. It can play a role in the remediation of toxic substances or in reducing the use of pesticides or other chemicals in the environment, and it has the potential to create a genetically engineered organism or substance that could harm ecosystem and human health.

■

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Introduction

Toxic substances are substances that have the capacity to cause adverse effects in living organisms by disrupting biochemical or physiological processes or functions, either as a more or less immediate result of exposure (acute toxicity) or as a result of continuing long-term exposure (chronic toxicity). Many toxic substances occur naturally in the environment, but over the past century human activities have greatly increased the concentrations of some of these substances in ecosystems and introduced a number of new toxic substances that are entirely of human origin. Two categories of substances are of particular concern: heavy metals, such as mercury, lead, and cadmium; and persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). These substances can pose a threat to the health of humans and the environment and have been linked to a wide range of effects, including cancer, cell mutations, birth defects, reproductive failure, and damage to the nervous system and bodily organs.

There are a number of reasons why these substances are of particular concern for human and environmental health. First, they are highly persistent. Persistent substances can remain bioavailable for long periods of time, increasing both the probability and the duration of potential exposure. For synthetic organic substances, persistence means that they do not degrade readily in the environment. Metals, being elements, occur naturally and are by definition persistent. For metals and other naturally occurring inorganic compounds, bioavailability is the key consideration when assessing the risks associated with toxic substances.

Second, even extremely low levels of these substances in the environment can have adverse effects on organisms that are continually exposed to them over long periods of time. Because the effects of exposure may not appear for several years or may show up only in subsequent generations, it is extremely difficult to anticipate or verify cause–effect relationships. Consequently, the effects of these substances have often been largely unanticipated.

Third, some effects of these substances are very subtle and are therefore difficult to detect and to attribute to specific causes. Exposure to lead, for example, is suspected of impairing mental function, eye–hand coordination, and memory, whereas some chlorinated organic compounds have been linked to changes in sexual characteristics and reproductive function in some species.

Fourth, the scope of the problem is potentially very large. POPs, for example, are largely products or by-products of the manufacture and use of commercial chemicals. The number of these chemicals is considerable, and little is known about the toxicity of most of them. The European Inventory of Existing Commercial Chemical Substances now lists 110 000 chemicals, and about 1 000 new ones are introduced every year (UNEP 1992). Many of these are either rare or totally unknown in nature. Consequently, many ecosystems now contain significant levels of substances that were not previously present or that were present at much lower levels. In the Great Lakes, for example, 362 substances of anthropogenic origin have been measured and are "considered to be unequivocally present" (Environment Canada et al. 1991). With improved knowledge relating to toxic substances, new measures are being put in place to better manage the manufacture, use, and disposal of chemicals in the future. However, the chemical legacy from the past is a continuing problem.

The scale of chemical production reflects another important aspect of the toxic substances issue — the extent of society's reliance on both natural and synthetic commercial chemicals. They are used in virtually every class of product and contribute greatly to the quality of life and material prosperity of modern industrial societies. In fact, the very foundation of current developed society rests on the use of these substances.

However, because society has become so reliant on chemical use, the toxic substances issue cuts across all human activities. Moreover, the environmental effects of these substances range from local to global, and their time horizon stretches far into the future. As a result, the outcome of this issue involves high stakes, not only in terms of ecological integrity and human health but also in terms of quality of life, economic prosperity, and community well-being.

Conditions and Trends

The information base for toxic substances

There are enormous limitations in the available data and information on toxic contaminants in Canada. The situation is little different in other nations of the world. In addition to major data gaps, many existing data suffer from poor quality control, laboratory testing that is environmentally unrealistic, and the lack of a good link to historic conditions (Nriagu 1994). Furthermore, the capacity to navigate through the maze of data and information that does exist, in order to interpret the meaning of all the signals, is in the earliest stages of development.

These limitations are compounded by an incomplete understanding of ecological processes. However, despite such impediments, a significant base of data, information, and understanding is available from which some early conclusions can be drawn about the challenge posed by toxic substances.

The following sections highlight some of the available information relevant to the toxic substances issue, focusing on sources and releases for the major classes of these substances, the effectiveness of various control options, and the implications of the use of these substances for ecological conditions and human health. With this range of data and information, a start can be made towards identifying and assessing the true costs and benefits of using toxic substances as an integral part of contemporary life.

Trace metals and inorganic compounds

Metals occur naturally and pervasively in the Earth's crust, surface water, groundwater, oceans, and atmosphere. In some localities, natural sources contribute significantly to ambient concentrations, but levels in the environment are also influenced considerably by emissions from human activities. Phenomena such as acidification of lakes and streams (from acidic deposition) and the warming of waters (caused by global warming and a range of other human-related factors) can have a significant influence as well.

Since the debut of the Bronze Age about 3800 BC, civilization has been characterized by an ever-expanding use of metals and an ever-increasing discharge of associated waste residuals to air, land, and water. Metals and inorganic compounds are now used in virtually all aspects of human activity. The resulting waste streams are, in turn, laden with these same substances, and traces of all metals and inorganic compounds that are mined and produced can be found throughout the ecosphere (at levels over and above natural occurrences).

The Task Force on Heavy Metals of the United Nations Economic Commission for Europe identifies the following nine elements as substances of concern: arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc (Pacyna et al. 1993). Antimony, cobalt, manganese, molybdenum, and vanadium are also common substances of concern in this category. Although these metals have the potential to induce a toxic response, some of them are also essential elements, which means that their deficiency can result in impairment of biological function. Selenium deficiency, for example, is a major concern in certain geological settings, such as in Finland and New Zealand; in these areas, selenium is added to livestock feed and agricultural lands to ensure adequate intake. Other metals known to be essential elements include zinc, copper, chromium, molybdenum, arsenic, cobalt, iron, and nickel.

Sources, releases, and ambient levels

A wide variety of natural and human-related sources contribute trace metals and inorganic compounds to the Canadian environment. The principal natural sources of trace metals to the atmosphere are windblown dust, volcanoes, biogenic processes, forest fires, and sea salt spray (Nriagu 1990). Table 13.1 provides estimated worldwide emissions of arsenic, cadmium, lead, and mercury from natural sources as well as estimated ratios of industrial to natural emissions. It should be noted that global estimates of natural emissions vary widely, with the result that estimated ratios of natural to anthropogenic emissions are very imprecise. The data in Table 13.1 are median values, each based on a range of estimated emission values derived from a number of data sources (Nriagu 1989).

Despite the wide differences in the absolute values reported by different investigators, most of the recent data support the conclusion that anthropogenic emissions of metals are comparable in magnitude to natural emissions and, in some cases, significantly greater (as in the case of lead — see Table 13.1; see also Jackson 1995, for example, for a review of the evidence for mercury).

The natural occurrence of anomalously high levels of metals in soils, stream sediments, and water has long been used by geologists as a guide in their search for potential ore bodies. This body of knowledge has been essential in placing "pollution" within an appropriate context of natural conditions. For example, some 11 375 naturally occurring mineralized sites are found in British Columbia. These sites are characterized by soil, sediment, rock, and water with elevated concentrations of a range of metals and metallic compounds. The majority of these would be classified as "contaminated sites" by current regulations governing the generation of hazardous waste (Downing 1994). Every mining district in Canada is probably characterized to some extent by naturally occurring soil, sediment, and water conditions that would exceed some regulations governing allowable releases to the environment (e.g., see Painter et al. 1994). New policy and regulatory initiatives recognize these natural variabilities. For example, the recent federal Toxic Substances Management Policy (discussed later in this chapter) provides direction to federal regulators and program managers to help ensure that natural background levels are taken into consideration in establishing targets and management strategies for naturally occurring substances.

Despite major advances in scrubbing technology, practically every high-temperature industrial operation still releases some residual metals to the environment. Principal sources include fossil fuel combustion, extraction of metals, waste and sludge incineration, and metal fabrication. Recycling of metallic waste products is a growing source (Nriagu and Pacyna 1988).

Table 13.2 summarizes atmospheric emissions of arsenic, cadmium, lead, and mercury from anthropogenic sources in Canada. At a more local level, Table 13.3 provides a listing of sources and loadings of lead, mercury, and PCBs to Lake Superi-

Table 13.1

Estimates of worldwide emissions of arsenic, cadmium, lead, and mercury from natural and industrial sources in the early 1980s

Metal	Emissions (t/year)		Estimated ratio of industrial to natural emissions
	Natural sources	Industrial sources	
Arsenic	12 000	19 000	1.6
Cadmium	1 400	7 600	5.4
Lead	12 000	332 000	28.7
Mercury	2 500	3 600	1.4

Source: Nriagu (1990).

or. As this table demonstrates, the atmosphere is a major pathway of exposure to these contaminants. Much of the input of these substances to the lake from rainwater runoff and tributaries may also be of atmospheric origin.

The extent of long-range atmospheric transport of metals of industrial origin varies considerably according to the source. Unlike major volcanic eruptions — during which particulate material sometimes reaches the stratosphere and can affect the whole globe within a few weeks, and whose particles have a residence time in the atmosphere of years — industrial sources are generally more local, and their emitted particles have a much shorter residence time (10–25 days or less). Recent work by Henderson and McMartin (1995) on metal levels in humus indicates that the fallout from the Flin Flon smelter in Manitoba becomes indistinguishable from background levels at a distance of 80–120 km from the plant. This and other similar studies (reported in Garrett 1996) suggest that the measurable impact of single sources on metal levels in the environment is limited to the order of 100 km from the source. However, when many anthropogenic sources are clustered together, the impact on metal levels is larger in both magnitude and regional distribution. For example, concentrations of mercury, lead, cadmium, and other contaminants have been found to increase in surface soil and forest litter along a transect running from northwestern Minnesota to eastern Michigan — i.e., towards sites of more intensive industrialization and greater density of sources of pollution (Nater and Grigal 1992; Nater et al. 1992; both cited in Jackson 1995).

The atmosphere is now recognized as a primary pathway for metals, especially in aquatic ecosystems. For oceans at the global scale, the ratio of total atmospheric deposition to river input from dissolved load has been estimated to be 4 for arsenic, 45 for cadmium, 57 for mercury, and 300 for lead (Nriagu 1992).

Table 13.4 provides estimates of the discharge of heavy metals to the world's major seas and oceans. Emissions from the intense industrial activity of eastern North America and western Europe are reflected in the high deposition rates for trace metals in the North Atlantic.

Figure 13.1 shows the annual wet deposition of lead in Ontario between 1981 and 1988. This figure also shows a strong decrease from the industrialized southern region to the more remote north.

The potential for airborne transport of toxic substances can be illustrated by constructing "atmospheric regions of influence." Three such atmospheric regions of

Table 13.2
Estimated atmospheric emissions of arsenic, cadium, lead, and mercury in Canada in 1990

Source	Emissions (t)			
	Arsenic	Cadmium	Lead	Mercury
Primary iron and steel	Negligible	Negligible	1.75	Negligible
Secondary iron and steel	Negligible	0.24	56.19	Negligible
Primary base metal industry	185.00	40.00	920.00	30.00
Secondary nonferrous copper	0.12	0.12	3.00	N/A
Secondary nonferrous lead	0.80	0.30	15.00	5.00
Secondary nonferrous zinc	0.15	0.38	3.00	0.00
Ferrous foundries	0.08	0.89	2.65	0.12
Ferro-alloys	N/A	N/A	0.69	N/A
Chlor-alkali	N/A	N/A	N/A	0.55
Chemical industry	N/A	0.00	8.60	0.06
Glass industry	N/A	0.27	7.77	0.09
Incineration	3.41	7.46	12.22	3.25
Fossil fuel combustion	1.41	1.02	3.07	0.02
Transportation	1.84	2.21	3.70	0.00
Cement industry	0.05	0.07	8.51	0.69
Coal-fired power plants	2.74	3.33	3.92	0.39
Base metal mining, milling, concentration, and drying	N/A	N/A	0.52	N/A

Note: N/A = no data available.

Source: Unpublished data, Pollution Data Branch, Environment Canada.

Table 13.3
Estimates of loadings of lead, mercury, and PCBs to Lake Superior, by source

Category	Loadings (kg/year)		
	Lead	Mercury	PCBs
Nonatmospheric			
Monitored tributary	9 665	86.4	21.6
Unmonitored area	5 189	37.8	6.2
Industry	5 124	39.0	10.0
Municipal	2 001	34.3	7.7
Combined sewer overflows	619	3.0	2.3
Direct runoff	7 013	40.2	18.1
Spills	140	2.0	0.0
Groundwater	0	0.0	0.0
Subtotal	29 750	242.7	65.9
Atmospheric			
Dry	4 655	282.6	31.4
Wet	62 396	374.4	124.8
Subtotal	67 051	657.0	156.2
Total	96 801	899.7	222.1

Source: Dolan et al. (1993).

influence from different parts of Canada are illustrated in Figure 13.2. They show that within any five-day period, half of the air reaching, for example, the Great Lakes basin arrives from within the envelope that is shown, and half arrives from beyond the envelope. The envelopes range from about 1 000 to 2 000 km in radius. They provide an effective illustration of how a given target can be influenced by distant sources of emissions.

Many persistent toxic substances, including those listed in Table 13.3, are slowly scavenged from the atmosphere. However, through successive emission, transport, deposition, and reemission processes (a phenomenon known as the "grasshopper effect"), they may migrate over short or long distances (Pacyna et al. 1993; Virtual Elimination Task Force 1993). Such substances can occur as gaseous compounds, as molecules adsorbed on particles, or as resuspended sediments and soil, and they may be found in water and biota. At any point, they may reenter the atmosphere or move between other environmental compartments such as land and water (Wania and Mackay 1993; Mackay et al. 1994). As a result of this recycling among environmental media, chemical substances are subject to repeated transport through multiple mechanisms; consequently, the atmosphere may be a more significant medium of transport for some substances than their atmospheric lifetimes alone would indicate (Han 1994). This phenomenon is also critical for understanding the behaviour of the POPs discussed later in this section. It is also significant in this context that, because volatile substances tend to evaporate more readily in warmer areas and condense in cooler areas, substances from lower latitudes inevitably move poleward as a result of this process. In this way, Arctic areas become a sink for contaminants from distant regions.

Table 13.5 summarizes worldwide industrial emissions of arsenic, cadmium, and mercury for the early 1980s, along with their principal sources. Lead, however, is by far the most common metallic contaminant in the environment. As Table 13.6 illustrates, substantial quantities of lead are released on every continent, making atmospheric lead contamination a global problem. For that reason — and because lead has also been the focus of extensive mitigation efforts — lead emissions and environmental concentrations are worth examining in more detail.

It is worth noting first, however, that the 1989 global emission total of 208 647 t, shown in Table 13.6, is 40% lower than the 1983 total of 332 000 t (Nriagu 1994). One of the major reasons for this decrease was the introduction of unleaded gasoline in North America. This measure was largely responsible for the dramatic reductions in North American lead emissions between 1970 and 1990, shown in Figure 13.3. In the United States, this reduction was 20-fold, whereas in Canada a 5-fold reduction was achieved.

The lead reduction story is further illustrated in Figures 13.4 and 13.5. In the former, historical changes in the total lead content of gasoline sold in Ontario are plotted against mean annual airborne lead levels in Toronto. The latter graph uses changes in the average lead content of cigarettes manufactured in Ontario to illustrate changes in environmental lead levels in southern Ontario's tobacco country. Similar trends have also been documented in the sediments of Lake Ontario (Mudroch 1993), the Strait of Georgia and Puget Sound (Macdonald and Crecelius 1994), Kusawa Lake in Yukon, Hudson Bay, and Amituk Lake on Cornwallis Island (Lockhart 1994). Together, all of these data sets illustrate how combined signals from human activities and environmental conditions can be used to monitor important trends.

Europe and Asia account for nearly 70% of the world's lead emissions (GESAMP 1989; see also Table 13.6). This situation has significant implications for the Canadian Arctic, which receives most of its lead contamination from these areas. A num-

Table 13.4

Estimates of the fluxes of heavy metals into the world's major seas and oceans

	Annual fluxes (μg/m²)						
Ocean/sea	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
North Atlantic Ocean	67	36	400	1 030	7.6	291	1 600
South Atlantic Ocean	5.4	2.9	31	80	1.8	24	127
North Pacific Ocean	13	7.1	77	200	6.5	57	312
South Pacific Ocean	1.3	0.73	7.8	20	3	6	31
North Indian Ocean	21	12	125	330	4.9	97	514
South Indian Ocean	2.1	1.5	17	50	3.7	13	69
North Sea	650	300	2 700	14 000	N/A	1 200	14 000
Black Sea	460	140	2 900	2 400	N/A	N/A	11 000
Northwestern Mediterranean Sea	<1 000	<1 000	4 200	29 000	N/A	N/A	34 000

Note: N/A = no data available.

Source: GESAMP (1989).

ber of different lines of evidence point to Eurasia as the predominant source of Arctic pollution, including meteorological analyses of wind patterns, aerosol trace element composition data, lead isotope composition data, and chemical transport modelling (Akeredolu et al. 1994). Figure 13.6 provides estimates of the amounts of lead arriving inside the Arctic Circle from Eurasian sources.

Successes and ongoing concerns
The experience with lead demonstrates that significant success is possible in reducing the chemical stress imposed on the environment by human activities. Some Canadian industrial operations have achieved spectacular emission reductions, mainly through modifications to their facilities. For example, in 1988, the Noranda Horne copper smelter emitted about 850 t of lead, nearly double the outputs of all other smelters in Canada combined, whereas emissions of arsenic were 110 t, or about 40% of total mining sector emissions. By 1993, however, process changes had reduced lead emissions to 216 t per year, a quarter of their 1988 level, and arsenic emissions had dropped to 23 t, or a fifth of their former level (MacLatchy 1992). Similarly, the Inco smelter at Sudbury has achieved significant reductions in emissions of heavy metals and other pollutants in concert with major efficiency improvements and cost savings. Further testimony to the kinds of improvements that are possible comes from the first report of the Accelerated Reduction/Elimination of Toxics (ARET) program (discussed later in the chapter), which documents substantial voluntary reductions by a number of organizations in emissions of a wide range of potentially toxic substances (ARET 1995a).

The significance of these successes cannot be overemphasized, and they must be recognized and encouraged. However, the broader context of these efforts must also be remembered. Thus, although lead emissions in North America have declined considerably since the 1970s, current deposition rates are still many times higher than the natural flux during prehistoric times, possibly by several hundredfold (Voldner and Smith 1987; Nriagu 1994, 1996). This kind of historic context is often missing from attempts to interpret data describing environmental processes and conditions.

Similarly, the spectacular improvements in lead emissions achieved in Canada and the United States (Fig. 13.3) must be weighed against the fact that most other nations in the world still use leaded gasoline. Further, even if leaded gasoline were completely eliminated worldwide, global lead emissions from other human sources would still exceed an estimated 80 000 t per year (Nriagu 1994).

In Canada, generally diminishing but still large quantities of metals continue to be released from human sources, especially from nonferrous metal smelters and refineries (Nriagu 1994; see also Table 13.2).

Effects on ecosystems
Contamination by trace metals and inorganic compounds is taking place throughout Canada. However, it has not been possible to estimate the overall magnitude of undesirable effects, because a causal link between elevated levels of toxic metals in food webs and systemic toxicity in field populations or impacts on ecosystem health cannot yet be established with any rigour. The problem is compounded by variable natural concentrations of pollutants and simultaneous exposure to a range of environmental toxicants.

The example of Belugas in the St. Lawrence estuary and gulf illustrates the complexity of the problem (Béland et al. 1993). Elevated levels of mercury and lead (as well as PCBs, dichlorodiphenyltrichloroethane [DDT], mirex, furans, and PAH metabolites) have been documented. Altogether, 40% of the animals studied showed a prevalence of tumours, 53% had a high

Figure 13.1
Annual wet deposition of lead in Ontario, 1981–1988

Note: Annual deposition in g/ha.
Source: Orr et al. (1992).

incidence of lesions of the digestive system, 45% of adult females had a high incidence of lesions of the mammary glands, and 50% of all animals had lesions to the respiratory system. Tooth loss and periodontitis were frequent, and there was some evidence of immunosuppression. Although the evidence suggests a causal relationship between exposure to contaminants and the health and reproductive impairments observed in the Belugas, it is not possible to isolate a specific contaminant and its effects or to untangle the effects of metals, inorganic compounds, and organic compounds.

Toxic effects of metals on every level of aquatic ecosystems have been documented. During the life of an organism, certain chemical substances that the organism consumes or absorbs are retained in its tissues and, as a result, increase in concentration within the organism to levels higher than in the surrounding environment. This process is called bioaccumulation. As organisms higher in food webs consume those below them, they also consume their entire chemical load. Persistent, bioaccumulative substances can become more concentrated or biomagnified as a result of this process. Although many metals and metal compounds have the potential to bioaccumulate in aquatic food chains, only methylmercury (the organic form of mercury) and possibly selenium biomagnify in aquatic organisms. In terrestrial food chains, it is reported that cadmium, methylmercury, and, possibly, lead have the potential to biomagnify. Methylmercury, for example, accumulates in carnivorous fish to concentrations thousands of times those found in ambient water (ATSDR 1993). In Lake Ontario, mercury levels in Herring Gulls are 135 times greater than levels in plankton. If the open lake water concentration of mercury is used as the starting point, the biomagnification factor from water to Herring Gull is 270 000 (Gill and Bruland 1990). Large, long-lived fish at higher levels in the food chain can accumulate large amounts of mercury. Biomagnification ranging from 80 000 to 640 000 times has been documented for mercury in Northern Pike from 63 Minnesota lakes (Sorenson et al. 1990).

The formation of methylmercury occurs in nature through both microbial reactions and abiotic processes. In other words, mercury methylation is a naturally occurring phenomenon that occurs whether the source of the inorganic form of mercury is geological or anthropogenic. Geological surveys since the early 1970s have shown that there are areas throughout Canada with high natural sources of mercury. As a result, elevated levels of methylmercury are commonly found in fish from lakes across the country, including lakes that are far removed from any industrial source of mercury (Rasmussen 1993). Natural levels can be augmented by mercury from anthropogenic sources. Interpretation of data on

Figure 13.2

Five-day atmospheric regions of influence for the Yukon, the Great Lakes, and the St. Lawrence River

Source: Summers and Young (1987); P. Summers, Atmospheric Environment Service, Environment Canada, personal communication.

Table 13.5

Worldwide industrial emissions of arsenic, cadmium, and mercury, along with principal sources, early 1980s

Metal	Emissions (t)	Principal sources
Arsenic	19 000	Smelting and refining of nonferrous metals (65%); fossil fuel combustion (12%)
Cadmium	7 600	Smelters (70%)
Mercury	3 600	Power generation plants (63%); waste incineration (31%)

Source: Nriagu and Pacyna (1988); Nriagu (1990).

Table 13.6
Global emission inventory for lead, by continent and source, 1989

Continent	Emissions (t)						
	Gasoline combustion	Fossil fuel combustion	Nonferrous metal production	Waste incineration	Cement production	Iron and steel	Total
Africa	12 316	628	4 421	N/A	85	86	17 536
Asia	44 006	4 209	21 323	207	867	3 713	74 325
Australia	2 000	411	2 775	62	12	118	5 378
Europe	47 579	3 477	13 041	537	641	4 278	69 553
North America	14 192	993	7 613	2 498	177	1 316	26 789
South America	8 796	195	5 422	N/A	98	555	15 066
Total	128 889	9 913	54 595	3 304	1 880	10 066	208 647

Note: N/A = no data available.

Source: Pacyna et al. (1993).

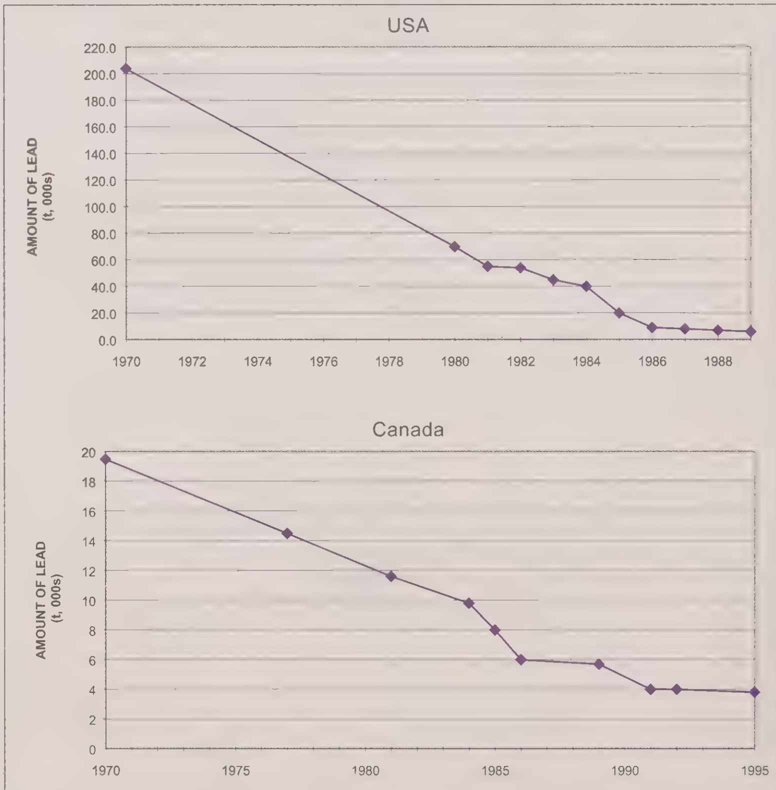
mercury levels must, therefore, take into consideration the nature of the sources.

At the interface between air and water is the *surface microlayer*. It is home to a number of microorganisms and provides critical habitat for the larvae and juvenile stages of many fish species. It is also particularly effective in accumulating metals and organic contaminants. For example, one study of tributyltin (an organic compound of the metal tin) in surface microlayers from polluted lakes and rivers of Ontario found that the LC_{50} concentration (the concentration that will result in the death of half of the tested organisms) was exceeded for Rainbow Trout larvae at 25% of the sites (Maguire et al. 1982). Box 13.1 summarizes some effects of tributyltin.

All fish-eating predators, such as mink, eagles, gulls, and terns, are subject to increased risk of exposure to mercury and other similarly bioaccumulated toxic substances. People who consume large quantities of fish are also at a more elevated level of risk than the general population. Included in this category are commercial and sport fishermen and their families, subsistence fishermen (especially Native Canadians), and certain immigrant groups, such as southeast Asians, who favour a high-fish diet.

Information about the effects of heavy metals and inorganic compounds on terrestrial organisms in Canada is still extremely limited, although growing. How-

Figure 13.3
Lead emissions, United States (1970–1989) and Canada (1970–1995)

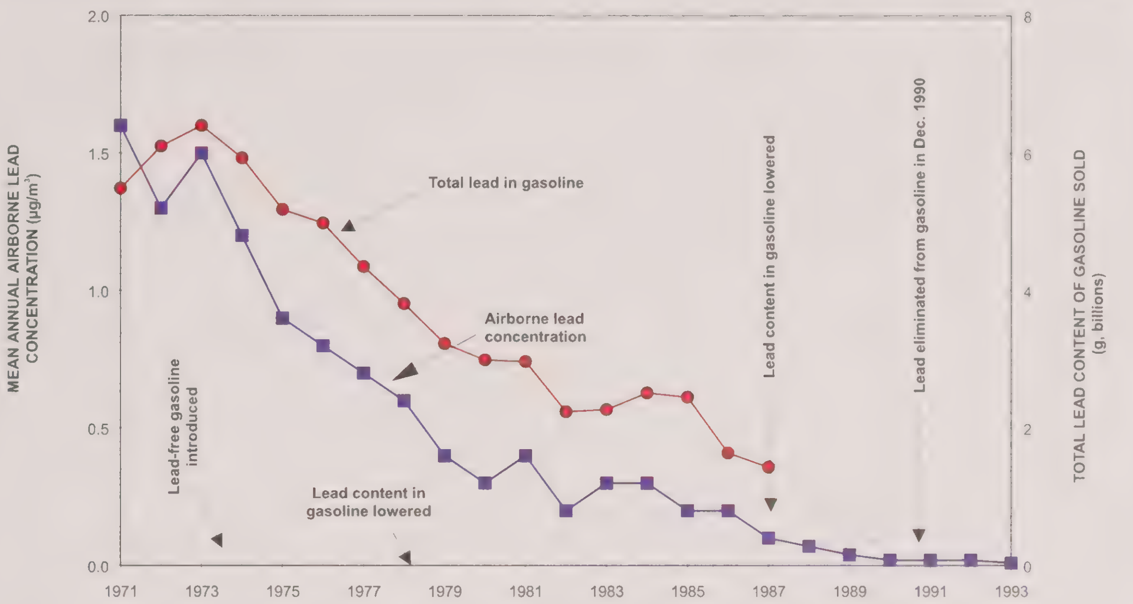


Note: Canadian emissions for 1995 are projected.

Source: Virtual Elimination Task Force (1993).

Figure 13.4

Total lead content of gasoline sold in Ontario and mean annual airborne lead concentrations in Toronto, 1971–1993



Source: Data for 1971–1991 from Reid et al. (1993); data for 1992 and 1993 from Ontario Ministry of Environment and Energy (1995).

ever, elevated levels of metals and inorganic compounds are known to lead to a variety of effects on terrestrial ecosystems, affecting microbial processes in soil, for example, as well as in the vegetation supported by the soil and in the species that feed on the vegetation.

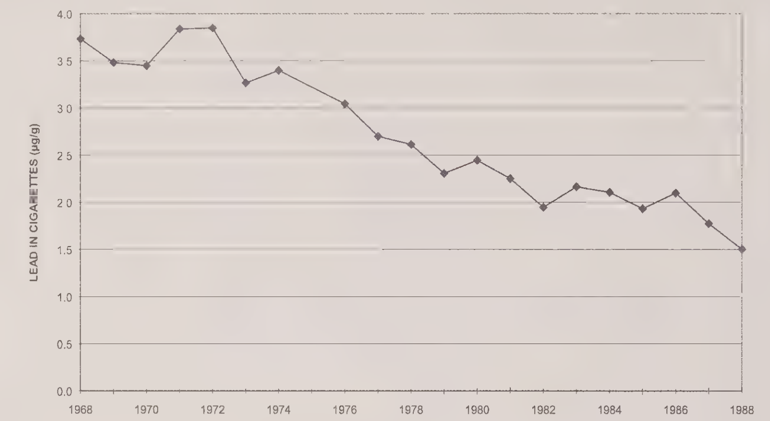
Arctic ecosystems are particularly vulnerable to contamination by toxic substances as a result of long-range atmospheric transport and bioaccumulation. The implications of these processes have been recognized only within the past decade.

Early evidence of the role of long-range atmospheric transport came when it was recognized that the biological systems of temperate and tropical climates were able to rid themselves of the long-lived fission products of nuclear tests. At the same time, Arctic ecosystems retained their radioactive burden, although the region received only 20–50% of the temperate and tropical deposition dose (Thomas et al. 1992). The human link was starkly documented during the period of atmospheric weapons testing, when the concentrations of cesium-137 were found to be about five times higher in circumpolar populations whose diet consisted largely of Caribou or Reindeer meat than in people who relied on other foods (Liden and Gustafsson 1967).

Analyses of Caribou kidneys and livers from many parts of the northern hemisphere have found elevated levels of metals. Figure 13.7, for example, summarizes results of studies of Caribou from various northern locations; all show elevated levels of cadmium, even in calves less than six months old, with a strong age-dependent variation demonstrating bioaccumulation over time (Mychasiw 1993). These levels have been associated with both natural sources and accumulated airborne contaminants in lichen, the Caribou's principal diet (see Chapter 9). To date, no health effects of high cadmium levels have been documented in either wildlife or humans, although health advisories on cadmium in Caribou livers and kidneys have been issued (Department of Indian Affairs and Northern Development 1996).

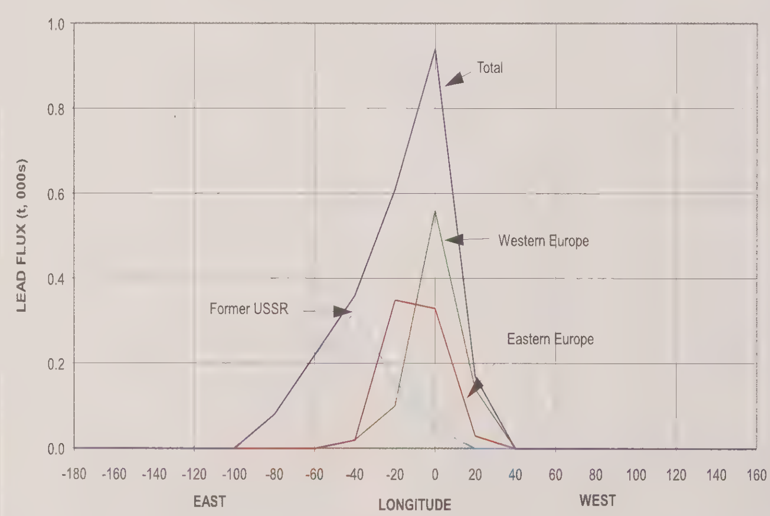
As discussed above with respect to mercury, interpretation of data on metal levels is complicated by the fact that in many remote locations throughout Canada, including Canadian Shield forests and Arctic ecosystems, background concentrations of metals found in the bedrock and soils are highly variable. This makes it difficult to determine the proportions of measured metals that are attributable to long-range atmospheric transport. Thus, conclusions about the importance of both industrial sources of metals and long-range atmospheric transport in remote locations cannot be drawn unless natural background levels of the metals are known.

Figure 13.5
Changes in the average lead content of cigarettes manufactured from tobacco grown in Ontario, 1968–1988



Source: Rickert and Kaiserman (1994).

Figure 13.6
The flux of lead into the Arctic Circle from Eurasia, by longitude and source



Note: About 95% of the airborne lead in the Arctic comes from sources in Europe and the former Soviet Union and crosses the Arctic Circle between about 100°E and 40°W, where it is then picked up by easterly winds and carried into Kalaallit Nunaat (formerly Greenland) and Canada. The predominance of these source regions is largely due to prevailing wind patterns and the more northerly location of emission sources in these areas. The estimate shown here is based on a single year's data (1979–1980), and details will vary from one year to the next as a result of fluctuations in the atmospheric circulation.

Source: Akeredolu et al. (1994).

Polar Bears from several locations in the Northwest Territories have been found to have highly elevated concentrations of mercury but relatively low levels of cadmium in their livers. Polar Bears sit at the top of the Arctic food chain.

Various studies have examined metal concentrations in the livers and kidneys of marine mammals, including Narwhals, Arctic Belugas, Walruses, Ringed Seals, Atlantic Pilot Whales, and St. Lawrence Belugas. Some of these concentrations — for example, cadmium in Narwhals from the Baffin Bay region — are within the critical limit for kidney dysfunction in mammals (Muir et al. 1992; Government of Canada 1994a).

The existence of distinct geographic patterns in the Canadian Arctic, such as the increasing concentrations of cadmium in Polar Bears from west to east and levels of mercury in Ringed Seals and other marine mammals that are higher in the western Arctic than in the eastern Arctic, suggests that metal intake is related to the geology of these regions (Muir et al. 1992). Recent work analyzing mercury data reveals a temporal trend superimposed on the spatial one. In both the western and eastern Arctic, mercury levels in recently sampled Belugas were found to be about twice as high as in Belugas sampled about a decade before. As well, mercury levels in Ringed Seals of the western Arctic were significantly higher in recent samples than in samples taken 15–20 years earlier (temporal data for Ringed Seals in the eastern Arctic were not available). This increase in mercury levels over time suggests that anthropogenic sources, in addition to regional geology, are a significant factor contributing to mercury levels in Arctic wildlife (Wagemann et al. 1995; Wagemann 1996).

Analyses of tissues and eggs of Arctic birds also show elevated levels of some metals (Braune 1993). Chapter 9 provides further discussion of contaminants in Arctic ecosystems.

Box 13.1

Tributyltin, the imposex effect, and shell thickening

Tributyltin (TBT) is a toxic compound previously found in most antifouling paints (i.e., paints used to inhibit the encrusting of barnacles and other kinds of marine life on boat hulls, fish pens, and other surfaces exposed to marine waters). TBT was introduced in the 1960s as a replacement for organomercury, arsenic, and lead boosters in copper-based paints. It became evident in the late 1970s that TBT not only leached out of painted surfaces but also had harmful effects on forms of marine life other than those it was intended to inhibit (Thompson et al. 1985).

During the 1980s, hazardous levels of TBT were detected in many estuaries and coastal waters all over the world. Concentrations of TBT as high as thousands of nanograms per litre in water have been reported (Bryan and Gibbs 1991; Garrett and Shrimpton 1995). At present, there are no Canadian guidelines for acceptable concentrations of organotins in fish and shellfish intended for human consumption, nor are there Canadian drinking water quality guidelines (Garrett and Shrimpton 1995).

Deleterious effects are seen in a wide range of marine life. Two of these effects — the imposex effect and shell thickening — are indicative of TBT contamination in marine life (Bryan and Gibbs 1991; Evans et al. 1995).

Imposex

The biota most sensitive to TBT contamination are the gastropods (the group of molluscs that includes snails, limpets, whelks, and conches), which exhibit morphological changes when exposed to TBT concentrations of 1–2 ng/L in water or when animal tissue TBT concentrations reach 20 parts per billion (ppb) dry weight (Bryan and Gibbs 1991). Imposex refers to the imposition and development of male reproductive structures, such as the penis and vas deferens, in female whelks. Over 40 different species have been reported to exhibit the imposex effect, although not all of these examples have been identified as being directly caused by TBT (Bryan and Gibbs 1991).

The imposex effect causes a decrease in gastropod populations because of the presence of fewer fertile females. Because of ecological interrelationships, other species are also affected. For example, gastropods periodically moult and create a new mantle in order to grow in size. They leave behind an empty shell, which hermit crabs then inhabit. Consequently, when gastropod populations decline, hermit crab populations decline also (Bryan and Gibbs 1991).

Imposex has been widely observed in whelks from the Strait of Georgia and the outer coastal waters of Vancouver Island. Surveys conducted since 1987 found the incidence of imposex to be 100% in waters around Victoria, and populations were also depleted (Saavedra-Alavarez and Ellis 1990; Tester and Ellis 1995). In Burrard Inlet (Vancouver Harbour), populations appear to have been eradicated. Even in B.C. waters where there is very little boat traffic, TBT has resulted in imposex. However, the incidence of imposex in these low-traffic areas has decreased, according to the most recent (1993) survey (Tester and Ellis 1995).

Shell thickening

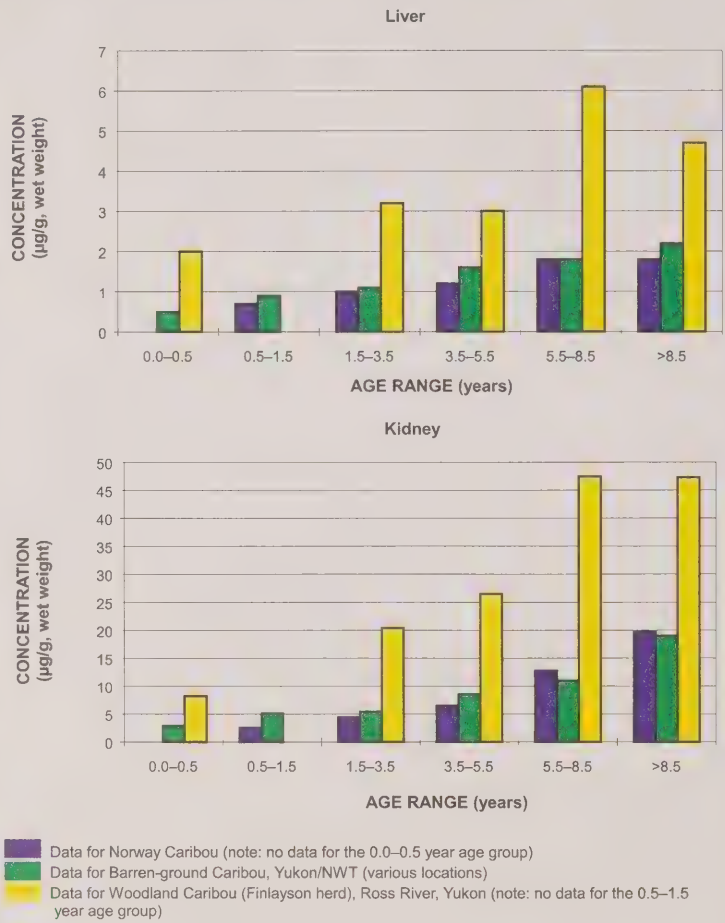
Oysters, when exposed to TBT, grow additional layers of shell, which are separated by chambers filled with gelatinous material. This effect can be reversed when the oysters are transferred into clean waters. Oyster shell thickening has been observed along the Canadian Pacific coast, notably in animals living near marinas or mariculture facilities (J.A.J. Thompson, Institute of Ocean Sciences, personal communication). Shell thickening can be fatal to oysters, and some believe that TBT contamination was a major cause of the decline of the European Oyster fishery off the east coast of England in the 1970s (Bryan and Gibbs 1991).

The danger of TBT includes its potential for bioaccumulation in animal tissues and the inability of most organisms to metabolize it. TBT can also accumulate in sediments. At a TBT-contaminated site, water samples may show a low presence of TBT; however, because of bioaccumulation, animal tissue or sediment will show much higher concentrations. The biomagnification potential of TBT has not been well studied; however, the available information suggests that organotin compounds are not likely to biomagnify (Bryan and Gibbs 1991; Garrett and Shrimpton 1995).

These concerns resulted in the banning of TBT as an ingredient in antifouling paints for most boats less than 25 m in length. In Canada, these regulations came into effect in 1989 under the Pest Control Products Act. *In many other countries where there have been local contamination problems, a ban on the use of TBT as an antifoulant has also occurred. Copper-based antifouling paints, which are considered much more inert, and low-leaching TBT antifouling paints (only two of these had been approved in Canada as of 1991) are being used instead today (Garrett and Shrimpton 1995).*

Controls on the use of TBT-based paints on pleasure craft appear to be producing results. For example, concentrations of TBT in sediments from Capital City Marina in Sidney, B.C., have decreased from a peak of 0.52 parts per million (ppm) to a surface value of 0.064 ppm (Stewart and Thompson 1994). However, TBT concentrations in the sediments of Vancouver Harbour, where most vessels are over 25 m, remain high, at approximately 0.4 ppm (Stewart and Thompson 1994). Additionally, analysis of the sediments from the deeper anoxic waters of the Strait of Georgia demonstrated that TBT was the major butyltin component. These results indicate that little metabolism of TBT is occurring (Stewart and Thompson 1994).

Figure 13.7
Mean cadmium concentrations in livers and kidneys of Arctic Caribou



Sources: Mychasiw (1993); Gamberg and Scheuhammer (1994).

Effects on people

Trace amounts of many metals and metallic compounds are important for human well-being. For example, trivalent chromium is considered an essential element in human nutrition (Government of Canada 1994b). At the other end of the spectrum, exposure to heavy metals above a certain level can result in acute poisoning, although cases of this are rare and mostly confined to workplace accidents.

In between these extremes lies a large grey area in which risk of injury increases with length of exposure and even very small amounts of some substances can give rise to toxic effects if exposure to them is sufficiently prolonged. The massive outbreak of mercury poisoning that occurred in Minamata, Japan, during the 1950s (Box 13.2) is a case in point. However, in many cases the effects of chronic exposure to low levels of metals and inorganic compounds are difficult to monitor and not well understood, particularly when a combination of substances must be considered. In general, long-term exposure to mercury, lead, and cadmium can cause damage to the brain, kidney, and nervous system and can adversely affect fetal development. At least some compounds of arsenic, cadmium, lead, and mercury are known to be carcinogenic (causing cancer), mutagenic (causing cell mutations), or teratogenic (causing birth defects). Box 13.3 summarizes some of the effects of lead contamination.

Nonoccupational exposure to mercury occurs almost always through the consumption of fish or shellfish. Mercury contamination is the leading cause of fish- and seafood-related health advisories in both Canada and the United States (Cole et al. 1992). Surveys of Ontario lakes undertaken between 1976 and 1990 found that over 90% of the Smallmouth Bass and Walleye populations and over 60% of the sampled Lake Trout populations showed mercury concentrations above the provincial health advisory guideline (RMCC 1990). About a third of the sampled Walleye populations have had a total human consumption ban placed on the largest size-classes of fish. These fish consumption advisories signal potential risk to human health, particularly to certain subpopulations that consume large quantities of fish (e.g., Native Canadians, sport fishermen and their families, and charter boat operators and their families) and to those that are at high risk of exposure (e.g., fetuses, breast-fed babies, and the elderly).

Because of heightened concern about the potential for mercury poisoning in the Arctic, where fish and other wildlife provide a vital component of the diet, a program was established in 1972 to assess levels of exposure and possible health effects. By 1992, 71 842 tests had been completed on 38 571 individuals. About 16 540 tests, or 23%, showed above-normal blood levels of mercury. However, of the 99 individuals who showed the highest blood mercury levels, only 11 showed symptoms that could be attributed to mercury poisoning (Wheatley and Paradis 1995; see also Chapter 9).

Arsenic, cadmium, chromium, and nickel, along with their compounds, have

been assessed for toxicity under the *Canadian Environmental Protection Act* (CEPA). For all of these, food is the major source of intake. Certain forms of all of these metals are classified as "non-threshold toxicants" — substances for which there is believed to be some chance of adverse health effects at any level of exposure (Government of Canada 1993a, 1994a, 1994b, 1994c).

Persistent organic pollutants

As with metals, people have used organic compounds for thousands of years. The dyes used by ancient cultures throughout the world are good examples. However, the second half of the 20th century has been accompanied by a dramatic rise in the manufacture and use of organic compounds. Many modern clothing fibres and construction materials, as well as fuels, rubber, plastics, and numerous other household and industrial products, are organic compounds. Most modern medicines are organic, and organic chemicals have also contributed to major increases in agricultural productivity.

Box 13.2
Minamata and mercury poisoning

In 1932, the Shin Nihon Chisso chemical factory was established in Minamata, Japan. Chisso used mercury as a catalyst in the production of ingredients for polyvinyl chloride (PVC) plastics (Ellis 1989). Inorganic mercury ($HgCl_2$ and $HgSO_4$) was discharged in the waste but was thought to be biologically inactive and therefore not likely to pose any serious threat. However, when discharged into the environment, the inorganic mercury was metabolized by aquatic microorganisms to form the much more toxic compound methylmercury. Methylmercury can bioaccumulate and biomagnify, thus reaching high concentrations in animal tissues at the top of food webs. In wildlife and humans, methylmercury causes a neuropathological degeneration, now commonly known as Minamata disease, that destroys brain cells that regulate balance and vision and results in tunnel vision, jerky and unsteady movements, and, in extreme cases, death.

Signs of the disease began to appear in 1951, although diagnoses were at first inconclusive, and the source of the illness could not be identified. In 1956, the number of victims reached an epidemic level, and trace metals in Minamata Bay began to be suspected of causing the sickness. In 1957, the local fishery was closed, but many of the people had no alternative food source and continued to eat the contaminated fish (Ellis 1989). Over 100 were killed by mercury poisoning, and another 1 742 were recognized by the Japanese government as being affected by mercury poisoning (Ellis 1989). The Minamata incident was the first publicized case of a human epidemic caused by the bioaccumulation of a toxic material.

A decade after the Minamata epidemic, reports of methylmercury poisoning in northern Ontario and northern Quebec began to appear. In some localities, natural sources of the metal were augmented, sometimes substantially, by mercury from mine tailings, fungicides, and chlor-alkali plants (associated with pulp and paper production) (Health and Welfare Canada 1984). As a result of these concerns, governments were forced to act: in 1970, Ontario imposed stringent controls on the amount of mercury that could be discharged to the environment. Because of their dependence on fish and other country foods, Native populations face the greatest risk of mercury poisoning. In high-risk areas, fishing has been restricted or banned outright, but these measures have sometimes had devastating effects on the economic and social fabric of Native communities. In 1976, Health and Welfare Canada launched a surveillance, monitoring, and health education program for Indian and Inuit communities across Canada (Health and Welfare Canada 1984). In 1985, the federal and Ontario governments also agreed to provide compensation to individuals affected by mercury poisoning (Shkilnyk 1985).

However, the development of many of these same organic compounds has had consequences far beyond those originally intended. It was the devastation resulting from inappropriate use of organic pesticides, for example, that led Rachel Carson to write *Silent spring* (Carson 1962). And it is organic compounds that are depleting the protective ozone layer in the Earth's stratosphere (see Chapter 15).

POPs are organic compounds that are resistant to breakdown by sunlight, biological action, or chemical processes. They are characterized by a capacity to bioaccumulate and biomagnify (Han 1994), and, because they are typically semivolatile, they can be carried great distances by atmospheric currents. All of these factors contribute to the extended periods (often several decades) for which they can remain in the environment.

Examples of POPs include many of the organochlorine pesticides, PCBs and polybrominated biphenyls (PBBs), chlorinated paraffins (used as fire retardants, plasticizers, and lubricant additives), brominated flame retardants, and various by-products of degradation, industrial processes, and combustion, such as PAHs, dioxins, furans, and hexachlorobenzene (HCB).

Several POPs, such as PCBs and DDT, are routinely identified and measured in environmental media, such as air, water, sediments, and biota. Analysis of concentrations of individual congeners (variants) of PCBs, dioxins, or furans is more difficult but well developed. Indeed, the capacity to identify minute quantities of contaminants has now far outstripped the capacity to relate any given contaminant or group of contaminants to ecosystem or human health conditions.

The detection of extremely low levels of POPs, however, requires highly sophisticated analytical techniques and instruments. Unfortunately, these are often expensive, and analytical costs for POPs are frequently two or more orders of magnitude greater than those for common pollutants, such as sulphur oxides and nitrogen oxides (UN-ECE 1994). These costs are a significant barrier to improving

society's understanding of the effects of these substances on the environment. Nonetheless, techniques available for the identification and analysis of POPs have advanced significantly through the past decade. The state of knowledge of POPs in the environment and their effects on biota is closely linked to these advances.

Sources, releases, and ambient levels

POPs are a very large and complex class of chemicals. Some enter the environment directly as a result of intentional use, such as the application of pesticides. Others may be released as a by-product of incineration or as a waste residual of industrial, commercial, or municipal operations. POPs can also be released into the environment as a result of spills or other accidental discharges. Because of the wide range of substances in this category, an assessment of sources is best conducted by chemical subclass.

Pesticides

Pesticides are a major global source of POPs. They include dozens of chemical compounds that are intentionally released into the environment to serve as herbicides, insecticides, fungicides, and rodenticides.

It must be emphasized that not all pesticides are POPs. Furthermore, many of the pesticides that are being used as substitutes for those that are persistent exhibit far greater acute toxicity. However, these substitutes are often specific to the target organism and have few effects on other species. The effectiveness of these chemicals is also much shorter-lived. This is the trade-off for the persistence of the organochlorine pesticides that are being replaced.

When applied, only 4–20% of a systemic pesticide is likely to be taken up by plants. Similarly, only a portion of a pesticide applied as a contact spray reaches the pest that is the target of the application. Spray drift, evaporation from plant, soil, water, and treated wood surfaces, surface water runoff, and percolation into groundwater are all pathways for the pesticides to enter into the surrounding environment. For some pesticides, the amount lost to evapo-

Box 13.3
Health risks due to environmental exposure to lead

There are no known beneficial effects of lead in humans or other animals. However, many adverse health effects are well documented for exposures to high lead levels — for example, anemia, renal damage, and encephalopathy.

Recent research data have shown that adverse health effects may occur at low blood lead levels that were previously thought not to result in adverse effects. Children are particularly susceptible to the toxic effects of low blood lead levels; the effects observed include lower scores on indices of mental development and lower birth weights. Exposure of pregnant women to lead may also result in exposure of the fetus and a higher risk of preterm delivery. Recent conclusions regarding the health risks in Canada have been based largely on the weight of evidence of neurotoxicity, while recognizing controversy over some individual studies.

In view of the recent health-related data, Health Canada has adopted the position that exposure to lead should be reduced as much as possible.

Exposures from all media (air, food, water, soil, consumer products) are usually taken into account in determining the need for control measures; blood lead levels are used as an indicator of total exposure from all sources. The actions taken with respect to lead in automotive gasolines, for example, were based on the best health data available at the time and an exposure assessment that indicated that 30–40% of children's blood lead was derived from lead in gasoline. In 1983, the Canadian government took action to reduce (starting in 1987) the maximum amount of lead that could be added to gasolines and, in 1986, decided to phase out lead in automotive gasolines by the end of 1992. Subsequently, the date of implementation was brought forward to December 1990.

Initiatives that have been implemented to reduce exposure to lead from all sources in Canada range from regulatory measures to a program of information and education and include:

- *the reduction and ultimate phaseout of lead additives in automotive gasolines;*
- *reduction in the permitted release of lead from ceramic ware;*
- *establishment of maximum limits for lead in certain foods — for example, tomatoes and tomato products, beverages, and infant formula;*
- *regulations that limit the amount of lead in protective coatings on furniture and other articles intended for children; on toys, equipment, and other products for use by children in learning to play; and on pencils and artists' brushes;*
- *support of a voluntary industry phaseout of lead solder in food cans;*
- *support of a voluntary industry agreement to eliminate lead from all consumer paints;*
- *revision of the Canadian guideline for lead in drinking water from 50 to 10 µg/L;*
- *implementation of recommendations made by Health Canada that the use of lead solder in plumbing for drinking water be discontinued; and*
- *implementation of a national information program to create an awareness of, and promote action to reduce, the health risks associated with removing leaded paint from older homes.*

There is evidence that the actions taken as a whole in Canada have had a significant health benefit: average blood lead concentrations in Canadian children have shown a steady decline, from about 19 µg/dL in 1972 to 12 µg/dL in 1984 and to 6 µg/dL in 1988.

ration approaches the total applied (Han 1994). Research to reduce these nontarget releases has resulted in vast improvements in spray technology and pesticide formulants in the last 10 years.

Some of the most persistent and toxic pesticides, such as DDT, aldrin, dieldrin, chlordane, and toxaphene, have been banned or restricted in some countries (Voldner and Li 1994). In Canada, under the *Pest Control Products Act*, none of these substances is allowed as a registered use, and all products, at time of registration and deregistration, are analyzed to determine their toxicological properties and their human health and environmental effects. However, such measures are far from universal; in many countries, restrictions have been imposed only within the last few years. The inconsistency of these restrictions from country to country is evident, for example, in the case of DDT, which has been banned in North America, Europe, and the former Soviet Union but continues to be used in Asia, Africa, and Central and South America (Han 1994).

Despite restrictions, most of these substances remain a significant source of concern, for two reasons. First, they are still being used in some countries (most often in developing countries). Because of their mobility, the use and production of POPs in any single area constitute a potential global source. Second, because of their persistence and mobility, continued global recycling of previously released quantities serves as an ongoing source (Han 1994).

There is much uncertainty about estimates of the production, total use, and emission of pesticides. Direct measurement of release to the environment is rare. Estimates are therefore made on the basis of production, sale, and use figures (and sometimes feedstock, import, and export figures). However, although pesticides are carefully registered and controlled in most countries, information on sales and usage (a prerequisite for estimating emissions) is often proprietary or confidential.

Table 13.7 shows annual pesticide sales in Canada. The dramatic increase in the number of active ingredients, registrants, and commercial products in the last decade reflects the wider variety of options now available to users, including the growing range of substitutes for persistent organic chemicals. However, trends in the overall volumes of pesticides used are not apparent.

The lack of more detailed data about pesticide production, use, emissions, and effects over time represents a significant impediment to adequate tracking of these substances.

Hexachlorobenzene

HCB was originally introduced in 1940 as a seed-dressing for cereal crops to prevent fungal disease. Its registration as an active ingredient for this purpose was discontinued in Canada in 1976 (L. Dunn, Agriculture and Agri-Food Canada, personal communication). HCB has also been used in various industrial processes — for example, as a fluxing agent in the manufacture of aluminum and as a peptizing agent in the production of rubber for tires. It is currently produced mainly through combustion processes involving chlorinated substances and as a by-product in the manufacture of certain chlorinated pesticides and industrial chemicals. In this latter group are chlorinated solvents, such as carbon tetrachloride, perchloroethylene, trichloroethylene, and chlorinated benzenes (Government of Canada 1993b; Han 1994). Table 13.8 lists the major sources of HCB entering the Canadian environment. The highest concentration of HCB in Canada has been detected in the Great Lakes region.

Polychlorinated biphenyls

PCBs are a group of industrial chemicals that were commercially produced worldwide on a large scale between the 1930s and 1970s. Their usefulness stems from their chemical stability and heat resis-

Table 13.7
Pesticide sales in Canada, 1981–1994

Year of sales	No. of active ingredients	No. of registrants	No. of products	Amount of active ingredients sold (t)	Year of survey
1981, 1982	24	115	780	N/A	1983
1983	89	210	1 680	N/A	1984
1984	120	240	2 150	N/A	1985
1985	184	320	2 600	39 259	1986
1986	212	312	2 350	32 968	1987
1987	215	336	2 605	>32 783[a]	1988
1988	223	355	2 790	>34 607[a]	1989
1990	240	498	3 397	33 964	1991
1994	250	N/A	N/A	N/A	1995

Note: N/A = no data available.

[a] Data were approximated to prevent the release of confidential business information. The active ingredient in pesticides is the chemical compound (or group of compounds) that contributes to the deterrence of pests by inflicting irritation or injury. It is through registering the number and amount of active ingredients sold annually that the Canadian government tracks pesticide use.

Source: Agriculture and Agri-Food Canada and Environment Canada (1995).

tance, and they have been extensively employed as components in electrical and hydraulic equipment and lubricants.

There are 209 PCB congeners — hydrocarbon substances with the same basic structure but different molecular weights as a result of the replacement of some hydrogen atoms by chlorine atoms. Each congener has different physical and chemical properties and thus a different potential for causing harm. Only a few, however, exhibit toxicity equivalency factors[1] that are high enough to be of concern.

In the 1970s, countries of the Organisation for Economic Co-operation and Development (OECD), including Canada, restricted the use of PCBs to closed systems. Manufacture for export to non-OECD countries continued in Europe until 1983 (Barrie et al. 1992). Most countries of the world now restrict the use of PCBs. To date, 16 countries prohibit the import of PCBs, whereas 6 others allow the import of PCBs only under special circumstances (Deocadiz 1995).

By the late 1980s, an estimated 1.2 million tonnes of PCBs had been produced worldwide (Tanabe 1988). Approximately 31% of this amount had already entered the global environment prior to use restrictions, roughly 65% is still in use in closed systems or is in controlled storage, and the remaining 4% has been destroyed in waste incineration plants (UN-ECE 1991).

Ongoing releases of PCBs to the environment occur from fires, spills, and leakages from closed systems; evaporation or leakage from landfills or PCB storage sites; incineration of waste containing PCBs (which were once used in a wide array of consumer products); and incomplete incineration of waste PCBs (Voldner and Smith 1987). Table 13.9 lists an inventory of PCBs in Canada as of 1991.

1. An international toxicity equivalency factor (TEF) index has been established that provides a scale for comparing the toxicity of substances with that of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), the most toxic of the dioxin congeners.

Dioxins and furans

Dioxins (polychlorinated dibenzo-p-dioxins, or PCDDs) and furans (polychlorinated dibenzofurans, or PCDFs) are two groups of chemicals with a similar chemical structure, each varying according to the number and position of chlorine atoms attached to the dioxin or furan molecule. There are 75 different dioxins and 135 different furans. The number and placement of their chlorine atoms also determine their physical, chemical, and toxicological properties.

The compound 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) is considered to be one of the most toxic synthetic compounds in existence. The furan congener, 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF), has similar toxicological properties but is an order of magnitude less toxic. Other dioxins and furans can be two or three orders of magnitude less toxic, and still others, by comparison, are considered to be relatively benign. Dioxins and furans usually enter the environment as a complex mixture of congeners. They are released from any process where chlorine and carbon are present at high temperatures (Government of Canada 1993c).

The most significant dioxin sources in the past have been the wood preservative pentachlorophenol, municipal incinerators, and pulp and paper mills using chlorine for the bleaching process. In Canada, the use

Table 13.8
Major sources of HCB in Canada

Source	Amount released (kg/year)
Manufacture of chlorinated solvents	24.0–69.7
Use of chlorinated solvents	≤122
Manufacture of pesticides	0
Application of pesticides	300–525
Incineration of HCB-containing wastes	Unknown
Long-range transport and deposition	510
Manufacture of chlorine and sodium chlorate	0
Hazardous waste landfills	Unknown
Emissions from other industries	Unknown
Effluents from municipal wastewater treatment plants	Unknown

Source: Government of Canada (1993b).

Table 13.9
Canadian PCB inventory as of 1991

Type	Amount (t)		
	In service	In storage	Treated
Bulk PCBs	10 800	5 750	N/A
PCB-contaminated mineral oil	2 000	3 600	53 000
Transformers containing PCB-contaminated mineral oil			
Pole-mounted transformers	310 000	N/A	N/A
Large power transformers	1 400	3 730	N/A
Transformers containing PCBs	6 300	7 500	N/A
Capacitors containing PCBs	175 000	280 000	N/A

Note: 1. N/A = not available.
2. Some amounts have been treated, for example, at the Alberta Swan Hills Waste Treatment Centre. There is also an unknown quantity of small capacitors in fluorescent light ballasts that require incineration.

Source: CCME (1993).

Table 13.10
PAH production and importation in Canada

Uses	Production (t)	Importation (t)
For commercial use[a]		
Naphthalene	>1 000	10–100
Anthracene	0.1–1	1–10
Fluorene	0.1–1	<1
Benzo(a)pyrene	0	<0.1
Chrysene	0	<0.1
Pyrene	0	<0.1
Presence in unleaded gasoline (0.0054% PAHs)[b]	1 500	N/A
Presence in creosote (63% of mixture)[c]	12 500	N/A

Note: N/A= not available.

[a] Limited information for 1986 based on voluntary reporting of commercial activities.
[b] Based on reported use of gasoline in Canada in 1989.
[c] Based on 1990 Canadian production of creosote. This represents a significant reduction. For example, 1940 production is estimated at 43 500 t.

Source: Government of Canada (1994d).

Table 13.11
Annual atmospheric emissions of PAHs in Canada, 1990

Sources	PAH releases	
	t	%
Anthropogenic sources		
Industrial processes		
Aluminum plants	925.0	21.0
Metallurgical (including ferro-alloy)	19.5	0.4
Coke production	12.8	0.3
Asphalt production	2.5	0.1
Petroleum refineries	0.1	<0.1
Combustion		
Residential heating		
Wood	474.0	11.0
Others	29.0	0.7
Open air fires/agricultural burning	358.0	8.3
Incineration		
Tepee burners	249.0	5.8
Municipal (with sludges)	1.3	<0.1
Industrial	1.1	<0.1
Transportation		
Diesel	155.0	3.6
Gasoline	45.0	1.0
Other	1.2	<0.1
Thermal power plants	11.3	0.3
Industrial combustion		
Wood	5.7	<0.1
Other	10.2	0.2
Commercial and institutional heating	2.7	0.1
Cigarettes	0.2	<0.1
Natural sources		
Forest fires	2 010.0	47.0
Total	4 314.0	100.0

Source: Government of Canada (1994d).

of pentachlorophenol is now restricted to heavy-duty wood preservation, such as treatment of wooden hydro and telephone poles, marine docking facilities, and railway ties, for which there is currently no environmentally preferable alternative. The dioxin content of pentachlorophenol has also been reduced. For example, 2,3,7,8-TCDD in currently formulated pentachlorophenol is not detectable using modern technology.

Similarly, with the introduction of the Pulp and Paper Effluent Regulations in 1992, under the federal *Fisheries Act*, pulp and paper mills have had to modify their processes to reduce the dioxins and furans in their effluents to nontoxic levels (see the "Forestry" component of Chapter 11). Pulp and paper mills are no longer considered to be a leading source of dioxins and furans.

A variety of combustion processes give rise to the formation of dioxins and furans, including wood burning and incineration of wastes. PCBs are the most significant potential source of furans, a fact that underlies the concern about accidental burning of PCBs (Government of Canada 1993c).

Polycyclic aromatic hydrocarbons
PAHs include a wide range of hydrocarbons. Some of these are produced commercially. Table 13.10 provides estimates of PAH production and importation in Canada. As commercial chemicals, PAHs are often produced specifically for the manufacture of other chemicals. For example, 70% of the PAH compound naphthalene in the United States and Japan goes towards making phthalic acid, which in turn is used in the manufacture of dyes, medicines, perfumes, and other synthetic products. PAHs are also common in some mixtures such as creosote, which is distilled from coal tar and is composed of 63% PAHs and 37% other distillates (Government of Canada 1994d).

PAHs are also produced as a result of the incomplete combustion of organic material. Although there are also some minor biogenic sources, including microorgan-

isms and plants, most PAHs released into the environment come from natural or anthropogenic processes involving combustion.

Fossil fuels (e.g., vehicle emissions), wood, tobacco, the incineration of garbage, coal liquefaction and gasification, and the production of coke, aluminum, iron, and steel are all significant anthropogenic sources of PAHs released into the atmosphere (Barrie et al. 1992; Government of Canada 1994d; Han 1994). Residential combustion, especially of coal and wood, accounts for about 60% of total European emissions (Berdowski et al. 1993, as cited in Han 1994). In Canada, forest fires are the largest single source of PAHs emitted to the atmosphere, and aluminum plants the largest anthropogenic source (Table 13.11).

Sources of PAHs entering soil and water include losses from creosoted materials (e.g., pilings, railway ties), accidental oil spills, atmospheric deposition, industrial processes (e.g., coal tar, asphalt), municipal effluents, and landfilling of PAH-containing wastes. It has been estimated that creosote-related releases alone could amount to up to 2 000 t per year, based on an estimated 20% rate of release of PAHs over the lifetime of the treated product (40 years for pilings, 50 years for railway ties) (Government of Canada 1994d).

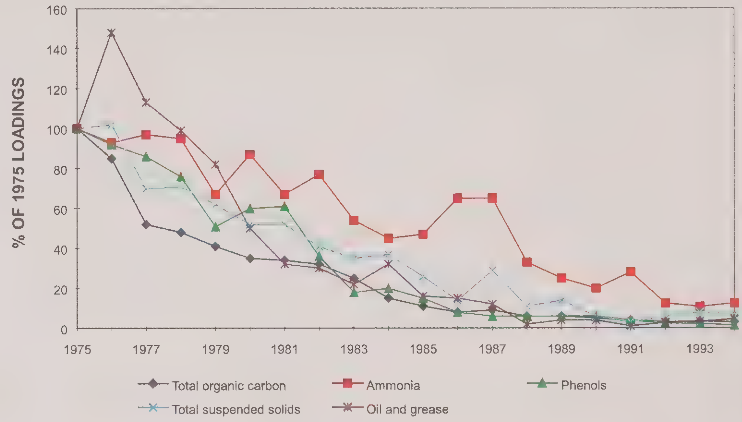
Benzo(a)pyrene, anthracene, benzo(a)-anthracene, phenanthrene, chrysene, fluoranthene, and pyrene are among the more common PAHs. Benzo(a)pyrene is often used as an indicator of total PAHs (Han 1994).

Successes and ongoing concerns

Since 1953, the Lambton Industrial Society, a cooperative of 15 industrial facilities in Sarnia, Ontario, has been encouraging and documenting improved practices and reduced emissions to water and air. Figure 13.8 shows annual loadings of five different pollutant categories to the St. Clair River between 1975 and 1994. Loadings in all categories have declined dramatically. The most significant improvement, from a toxic substances perspective, has been the 97% decline in loadings of total organic carbon.

Figure 13.8

Annual loadings to the St. Clair River, 1975–1994, by the members of the Lambton Industrial Society, as a percentage of 1975 loadings



Source: Data for 1975–1992 from Lambton Industrial Society (1992); data for 1993–1994 provided by the Lambton Industrial Society.

As a further example of actions taken to date, many POPs have been deregistered in Canada under the *Pest Control Products Act*. This has resulted in the removal of thousands of products over the last 15 years. Substances such as toxaphene, DDT, aldrin, dieldrin, mirex, chlordane, endrin, HCB, and heptachlor, for example, are no longer registered for use in Canada. Producers have adjusted by adopting new approaches and new products. Agriculture and Agri-Food Canada, with the active participation of organizations such as the Canadian Horticultural Council and the Crop Protection Institute, has been encouraging the use of integrated pest management. Integrated pest management aims to suppress pests effectively, economically, and in an environmentally sound manner by combining biological, cultural, mechanical, behavioural, and, when necessary, chemical controls in the most optimal fashion.

Figure 13.9 shows the effects of the tightening of pulp and paper mill effluent regulations in the early 1990s on mean annual discharge of total adsorbable organohalides (AOX) from mills in British Columbia and related fish survival rates. These trends illustrate a successful linking of industry response to a changed regulatory regime.

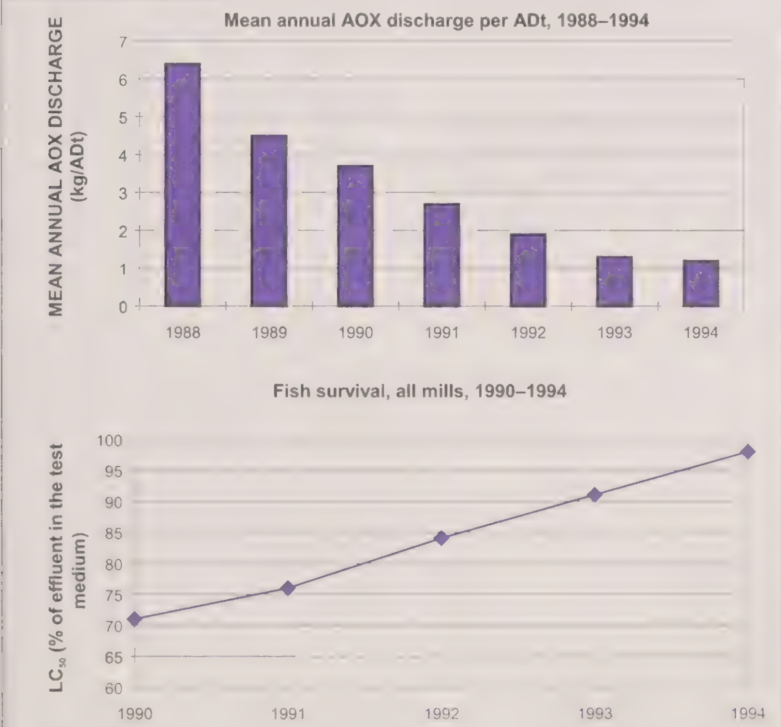
The encouraging trends shown in Figure 13.9 are matched by trends in discharges of biochemical oxygen demanding materials (BOD) and total suspended solids (TSS) and a range of bioindicators, including dioxin and furan concentrations in whitefish from the Fraser River (B.C. Ministry of Environment, Lands and Parks 1995) and in Great Blue Heron eggs in the Strait of Georgia (Mahaffy et al. 1994). Levels of dichlorodiphenyldichloroethylene (DDE, a breakdown product of DDT) and PCBs in Double-crested Cormorant eggs from 1970 through 1992 in the Strait of Georgia (Mandarte Island), the Great Lakes (North Channel, Lake Huron), the St. Lawrence Estuary (Île aux Pommes), and the Bay of Fundy (Manawagonish Island) all show similar improvements.

In the Great Lakes basin ecosystem, however, where reductions in point source emissions are continuing (see, for exam-

ple, ARET 1995a), bioindicators of ecosystem conditions are not all continuing to improve. As one research group has reported, "while concentrations of many contaminants have decreased in water, sediment, and biota in the Great Lakes since the early 1970s, concentrations have since stabilized and in some cases are increasing" (De Vault et al. 1995; see also Colborn et al. 1990; IJC 1990, 1992, 1994, 1995; Environment Canada et al. 1991). An illustration of this condition is provided in Figure 13.10, which shows PCB levels in Coho Salmon in lakes Michigan and Erie from 1980 to 1992. Other contaminants, such as DDT, show similar trends (see Chapter 6).

The cause of this stabilization, or "plateau" effect, is some combination of processes that include continuing (although reduced) emissions from point sources, continuing and perhaps increasing emissions from non-point sources (e.g., groundwater-borne contaminants from hazardous waste sites, agricultural runoff, urban runoff, and urban smog), accidents and spills, long-range transport of airborne pollutants, recycling of contaminants from bottom sediments, and the retention of bioaccumulated substances in the food web.

Figure 13.9
Mean annual AOX discharge from pulp and paper mills in British Columbia, 1988–1994, and fish survival rate, all mills, 1990–1994



Notes:
1. LC_{50} = lethal concentration 50. The concentration of test substance (in this case pulp mill effluent) in water that kills 50% of a test batch of fish within 96 hours. It is usually expressed in terms of weight of test substance per standard volume of water (mg/L). In this case, the left axis is the percentage of ideal LC_{50} achieved. An "ideal" LC_{50} value is 100%, meaning that more than 50% of the test fish can survive in effluent at 100% concentration after 96 hours. Higher values of LC_{50} represent improved fish survival.
2. ADt = air-dried tonnes.

Source: B.C. Ministry of Environment, Lands and Parks (1995).

The Great Lakes basin ecosystem can be considered relatively advanced in terms of a cycle that includes not only heavy industrialization and high levels of initial pollution but also subsequent shifts in industrial structure and processes and general public policy and attitudes that have led to reduced pollution. However, there is another side to this story. Initial efforts at pollution control are typically low in cost and high in results. With time, improvements get more difficult to achieve, and costs increase. Simultaneously, the relative importance of the processes influencing the nature and extent of both imposed chemical stress and the responses of the ecosystem are shifting. For example, point sources of contaminants are now less significant, whereas long-range transport of airborne pollutants into the basin from distant sources and non-point sources within the basin are more dominant. Thus, continued efforts to reduce point sources from industrial activities will still help to alleviate environmental stress but will become less and less significant to an overall improvement as successes are achieved.

This conclusion has important implications for environmental monitoring and its application to policy development and decision-making. If the monitoring priority is aimed at point sources and they are becoming less and less dominant, the monitoring system and the policy development that it feeds are vulnerable. The lesson is that monitoring and policy require a strategic approach that takes into account the nature of the whole system that is operating, not just one important part.

The situation in the Great Lakes will likely be repeated in other parts of Canada and the world as time progresses. Because it is such a leading situation, it is important to track conditions in the Great Lakes closely. Similar trends must also be watched for in other ecosystems in Canada and abroad.

Effects on people and ecosystems
Concerns regarding POPs extend throughout the world. However, because high-latitude regions are a global sink for POPs, and because these regions are already characterized by a low degree of biodiversity and biological activity, these substances are a special concern to Canada and other northern countries (Wania and Mackay 1993; Nriagu 1994). Some of the more volatile POPs have been found at higher levels in Arctic biota than in biota from more southerly latitudes, even though there is no known source of these substances in the Arctic (Muir et al. 1992; Iwato et al. 1993).

The vulnerability of wildlife and people in northern regions is further enhanced by the simplicity of some of the food chains, such as the lichen to Caribou/Reindeer to humans chain typical of many northern areas (Lockhart et al. 1992; Muir et al. 1992; Thomas et al. 1992). This vulnerability is demonstrated by findings that levels of PCBs and DDT in the breast milk of some Native women in the eastern Arctic are now from five to seven times higher than those of women living in the Great Lakes basin. This finding is surprising, considering that most POP levels in wildlife from the Great Lakes are up to 10 times higher than those in comparable Arctic species. The resolution of this apparent contradiction lies in the higher consumption of country foods and the greater proportion of fattier foods (e.g., blubber) in the North than in the South.

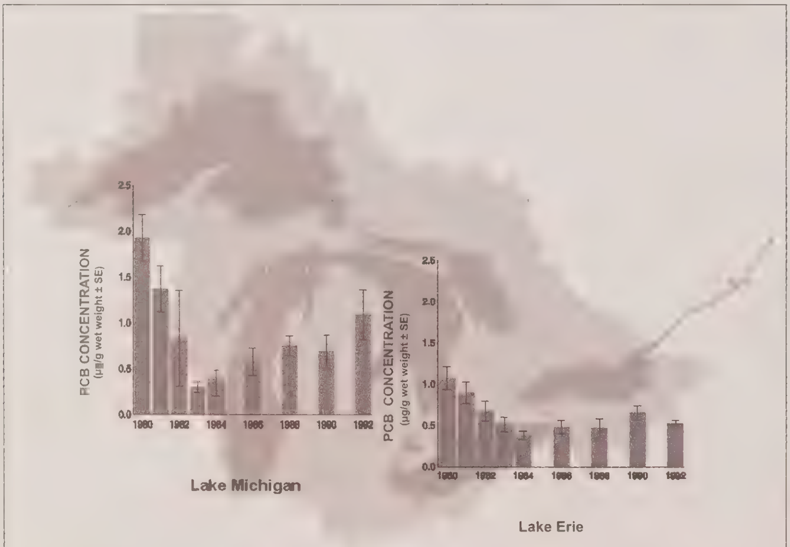
Even if ambient concentrations of POPs in the environment are extremely low today — low enough that on their own they pose little or no immediate risk to biota, including humans — they can still give rise to serious effects over the long term. Significantly, 9 of the 11 substances listed by the International Joint Commission as "critical pollutants" for the Great Lakes are POPs.

Increased understanding of the behaviour of POPs has led to growing apprehension regarding the implications of long-term effects that may not be recognized in the initial phases of use. Research on laboratory animals and corresponding observations of wildlife exposed to near-ambient levels of POPs and some metals demonstrate that a broad range of potentially serious effects can be associated with chronic low-level exposure. These include reproductive, metabolic, neurological, and behavioural abnormalities, immunity suppression leading to susceptibility to infections and other life-threatening problems, increasing levels of cancer, and long-term reproductive and intergenerational effects (IJC 1994). Although the direct evidence of chronic human health effects is less extensive, enough similarities or parallels exist with wildlife and laboratory work to raise concern (Colborn and Clement 1992; IJC 1993, 1994; Virtual Elimination Task Force 1993). A summary of cause–effect linkages of persistent toxic substances suggested by work in the Great Lakes basin ecosystem is provided in Table 13.12.

Many of these effects are subtle and not necessarily linked to mortality. For example, a broad range of POPs can mimic the female hormone estrogen. The resulting estrogenic effects include disruption of the endocrine system and associated effects, including reproductive and immune system dysfunction, neurobehavioural and developmental disorders, and possibly certain forms of cancer (Colborn et al. 1990; Environment Canada et al. 1991; Colborn and Clement 1992; Han 1994). Some other synthetic chemicals mimic growth hormones and other steroid molecules. Many of these chemicals are in common household and industrial use, as surfactants, texturing agents, and plasticizers. Among the substances implicated in the disruption of endocrine systems are PCBs, dioxins, atrazine, HCB, other organochlorines, and PAHs (Colborn et al. 1993).

Because the developmental processes of any embryo or fetus are highly sensitive to disruption (Bern 1992; Colborn and Clement 1992; Peterson et al. 1992), embryonic exposure to chemical compounds is a particularly serious concern. A healthy debate is currently raging in scientific circles about the endocrinological (and other) effects of POPs on human beings and, in particular, about whether

Figure 13.10
Mean PCB levels in Coho Salmon fillets from Lake Michigan and Lake Erie, 1980–1992



SE = standard error

Source: Great Lakes National Program Office, U.S. Environmental Protection Agency, as reported in De Vault et al. (1994).

the correlations that have been made between wildlife and human health are justifiable. This debate once again raises the question of how society should respond to risk under conditions of uncertainty. Should it act now on the basis of incomplete evidence, or should it wait for irrefutable proof? If it opts for the latter course, it can then act with certainty. But if the problem is real, such action will come too late for those who have been affected in the meantime, and perhaps for their offspring as well.

Regardless of this debate, the implications of these concerns are profound. They would, if the fears of some scientists prove to be true, cause a significant shift in much contemporary decision-making and in the risk assessment that supports it: lists of suspected toxic substances would expand greatly, controls for sewage effluent and terrestrial runoff would tighten dramatically, and the nature of many consumer products would alter. Perhaps no other issue related to toxic substances is as potentially important as this one. Certainly, with no other aspect of the toxic substances issue is the need for caution more apparent.

Radioactive substances

Radioactive substances present a risk to the living world because their ionizing radiation can alter essential cellular components and genetic material (deoxyribonucleic acid, or DNA). A range of harm can occur, but the dominant concern is cancer. For these and other reasons, radioactive substances, including radioactive wastes, are strictly controlled by the Atomic Energy Control Board, under the *Atomic Energy Control Act*.

Radioactive wastes fall into three broad classes:

1. *High-level waste* — used fuel that has been discharged from nuclear reactors; some elements remain hazardous for tens of thousands of years.
2. *Low-level waste* — includes *historic* waste, mostly from radium and uranium refineries, and *operational* waste, such as nonfuel waste from nuclear reactors, radioactive waste from decommissioning of nuclear facilities, radioisotopes from hospitals and laboratories, and contaminated used equipment, materials, cleaning rags, and protective clothing. Most low-level waste decays to nonhazardous levels in less than 500 years.
3. *Uranium mine tailings* — radioactive waste generated during the mining and milling of uranium ore. Uranium mine tailings also commonly contain toxic substances such as arsenic and a range of heavy metals. All of these substances are naturally occurring, but the potential for radiation exposure or release of associated toxic substances increases when uranium ore is brought to the surface and milled. Uranium mine tailings remain radioactive for tens of thousands of years, and some of the associated toxic substances remain hazardous indefinitely.

Naturally occurring and radioactive radon gas has also been a concern in some Canadian localities, such as Port Hope, Ontario, the site of Canada's first radium refinery, as well as several uranium mining communities, including Elliot Lake and Bancroft in Ontario and Uranium City in Saskatchewan (Eaton 1990). The occurrence of naturally high levels of radon gas is not restricted to mining communities. A national survey conducted between 1977 and 1980 reported

Table 13.12

Reported linkages between observed biological effects and persistent toxic substances

Species	Observed biological effects	Inferred chemical cause
Bald Eagle	Eggshell thinning; embryo mortality; adult mortality	DDE, dieldrin, PCBs
Forster's Tern	Embryo mortality; deformities	PCBs
Double-crested Cormorant	Embryo deformities; eggshell thinning	Dioxins, PCBs, DDT
Snapping Turtle	Embryo abnormalities; embryo mortality	PCBs
Mink and otter	Reproductive dysfunction	PCBs, dioxins
Brown Bullhead	Liver and skin tumours	PAHs
Lake Trout	Inability to reproduce normally; hatching difficulties and fry mortality	PCBs
Herring Gull	Embryo mortality; porphyria; thyroid hyperplasia; vitamin A depletion; deformities; feminization; poor parenting	Dioxins, PCBs, DDT
Human offspring	Short-term memory deficits (visual, verbal, quantitative, pictorial); growth retardation; activity retardation	PCBs
Human offspring	Hyperactivity; permanently reduced intelligence; neurobehavioural abnormalities	Lead
Human offspring	Learning and motor skill deficits	Mercury

Source: Adapted from Virtual Elimination Task Force (1993).

that elevated levels of radon were found in houses in Winnipeg and Regina, although the levels did not, in general, lead to an unacceptable additional risk to homeowners (Létourneau et al. 1994).

As of 1 January 1996, 21 nuclear power plants were operating in Canada — 19 in Ontario, 1 in Quebec, and 1 in New Brunswick. As of the end of 1992, the accumulated inventory of used nuclear fuel was about 900 000 bundles — enough to fill about seven Olympic-sized swimming pools (Auditor General of Canada 1995). No permanent solution to the problem of high-level radioactive waste management and disposal has been found. A concept for disposal of nuclear fuel waste deep in geologically stable formations of the Canadian Shield is currently under review by a panel established under the Federal Environmental Assessment and Review Process Guidelines Order.

By 1992, Canada had accumulated about 150 000 m^3 of operational low-level radioactive waste, and about 6 000 m^3 were being added annually. No approved disposal technology or any disposal facilities for low-level waste exist in Canada (Auditor General of Canada 1995). There are currently 18 licensed interim storage facilities.

Also by 1992, the accumulated total of historic low-level radioactive waste stood at approximately 1.2 million cubic metres. Most of this is linked to the radium industry and the early years of uranium production. No permanent management or disposal strategy has been established.

About 200 million tonnes of low-level radioactive uranium tailings now exist in Canada, covering an area of about 1 500 ha (see Chapter 11) and representing about 3% of mine tailings in Canada (Auditor General of Canada 1995). No permanent management or disposal strategy has been established.

The Auditor General of Canada (1995) estimates that total costs for disposing of Canada's radioactive waste over the next 70 years will be at least $10 billion. Although the dominant responsibility lies with waste producers, mainly the nuclear utilities, the federal government's share is likely to be around $850 million. However, that amount could increase if the government had to assume residual responsibilities for any of the waste producers.

Toxic substances and biotechnology

Biotechnology is defined as the application of science and engineering in the direct or indirect use of living organisms or parts or products of living organisms in their normal or modified forms. The relevance of biotechnology to the toxic substances issue includes both its role in providing useful tools for the remediation of toxic contamination or for reducing the use of pesticides or other chemicals in the environment and its potential for creating a genetically engineered organism or substance that could harm ecosystem and human health in much the same way as a more traditionally defined toxicant.

The growth in the biotechnology industry has been phenomenal — its worldwide potential is expected to reach $75 billion by the year 2000, an increase from $40 billion in 1990 (OECD 1994). In Canada, the number of biotechnology companies has grown as well, from 110 in 1986 to 396 in 1993 (Contact International 1993). A precedent was set in both the United States (1981) and Canada (1982) when patents were issued for the first genetically engineered microorganism (Belcher and Hawtin 1991). This event has provided private industry with the market incentive for further research and development in genetic engineering.

Organisms that could pose potential safety concerns, including genetically engineered organisms, are regulated by federal departments. Provisions under agricultural legislation (covering seeds, feeds, fertilizers, veterinary biologics) and Health Canada legislation (covering pest control products and novel foods) are already in place to ensure the safety of products containing organisms with respect to human health, animal health, and the environment. The federal government's proposal for the renewal of CEPA, published in late 1995, confirms the intent to develop new provisions under CEPA to deal with living products of biotechnology not already regulated under other government legislation. This proposal is currently out for public consultation. Once CEPA regulations are put in place, evaluations of products falling under CEPA (e.g., bioremediation agents) can begin.

Biotechnology is an important emerging issue, and CEPA is not intended to be the only instrument for controlling its products. It is intended, however, to serve as a safety net that will regulate aspects of those products that are not covered by other federal legislation.

Toxic substances in waste

The generation and management of waste represent a significant cost to society in terms of dollars, resources forfeited, and resulting physical, chemical, and biological stress imposed on the environment. For all these reasons, waste reduction is a dominant motivation for the current trend towards life cycle analysis and design for sustainability (discussed later in this chapter).

Wastes are classified by their origin, their contents, or their designated disposal method. While variations in terminology and policies exist from province to province, wastes in Canada are generally classified in the following categories:

- solid waste (nonhazardous solid waste that would normally go to a municipal landfill for disposal; it includes residential, industrial, commercial, and institutional [ICI], and construction and demolition [C&D] waste);
- heavy industrial waste (e.g., mining, agricultural);
- hazardous (special) waste;
- biomedical waste;
- municipal wastewater;
- dredge spoil waste; and
- radioactive waste.

Not all wastes are toxic. However, certain waste streams are sources of toxic substances. Hazardous waste, biomedical waste, and radioactive waste, although subject to special management treatment practices, all have agents that potentially present some level of risk to human health and the envi-

ronment. In addition, solid waste and municipal wastewater (sewage and sewer effluent) contain toxic substances that are discharged — in some cases, untreated — into the environment (notwithstanding, with respect to solid waste, strict provincial regulations regarding landfills and incinerators). Although concentrations of these substances are low, they are nonetheless significant because of the size of these waste streams (B.C. Ministry of Environment, Lands and Parks 1993; Sierra Legal Defense Fund 1994).

Canada is one of the largest generators of waste, per capita, of all OECD countries (Environment Canada 1993). In 1982, an estimated 3.3 million tonnes of hazardous waste were produced in Canada. This increased to 5.9 million tonnes by 1992 and constituted up to 20% of Canada's waste (Apogee Research 1995). Of this amount, the chemical industry was responsible for 47% and the metals industry for 38% (Meakin 1993).

An examination of residential solid waste in four cities in British Columbia demonstrated that hazardous waste constituted between 0.8% and 4.8% of the waste stream (Gartner Lee Ltd. 1991). Concern also exists for the discharge of hazardous waste in municipal wastewater. Some 200 chemicals have been identified in this waste stream in Canada (Sierra Legal Defense Fund 1994).

The federal, provincial, and territorial governments have established a goal of reducing waste output to 50% of the 1988 level by the year 2000 (Environment Canada 1993). Based on 1992 data from the Canadian Council of Ministers of the Environment, a 13% per capita reduction has been achieved.

Estimates of the amounts of hazardous wastes generated are far from exact, especially in countries lacking the technical expertise to conduct waste inventories. Estimates of international transfers are even less precise. In many less developed countries, systematic monitoring does not exist; where it does exist, methods are not uniform, and definitions are inconsistent. Further, in countries lacking effective infrastructure, transfers across boundaries can take place without the knowledge or beyond the control of governments. As a result, actual quantities probably significantly exceed official estimates in many countries.

At this stage, estimates of the global volume of hazardous wastes generated annually range from 300 to 500 million tonnes (UNEP 1994). This amount is constantly increasing in parallel with world production of chemicals (Kummer 1994). The portion of this that is involved in transboundary shipment is unknown (see World Resources Institute et al. 1990).

At the global level, the first tangible signal of action to deal with the problem was the 1989 signing of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. This convention came into force in 1992.

Canada's Export and Import of Hazardous Wastes (EIHW) Regulations, which introduced strict controls on imports and exports of hazardous wastes and allowed Canada to ratify the Basel Convention, came into force on November 26, 1992.

Negotiations at the Third Conference of the Parties led to a consensus decision that calls for an amendment to immediately ban exports of hazardous wastes destined for final disposal from developed to developing countries; and to phase out by December 31, 1997, and prohibit as of that date, such exports when destined for recycling.

Since the implementation of the EIHW Regulations, Canada has not consented to any exports of hazardous wastes, whether for disposal or recycling, to developing countries. In addition, the regulations prohibit the export of hazardous wastes to any country that has banned their import.

Accidents and spills

The December 1984 accident at the Union Carbide pesticide plant in Bhopal, India, released 40 t of methyl isocyanate, leaving 3 400 people dead and 60 000 with chronic ailments. Some 3 000 farm animals were also killed. The 1988 fire in Saint-Basile-le-Grand, Quebec, spread PCBs and other contaminants over a wide area and led to the evacuation of 3 500 people. Such catastrophic accidents focus attention on the toxic substances issue and provide impetus for improved safety, operating, and emergency response procedures.

Less recognized but perhaps of greater overall impact are the thousands of small operational accidents and spills that occur every day. For example, in the eight Great Lakes states and Ontario, there are about 3 000 significant accidental releases of hazardous substances per year. These accidental releases may significantly exceed the impact of regulated point source discharges. Two styrene spills into the St. Clair River, for example, were found to be 1 428 and 58 times greater, respectively, than the annual point source discharges of the facilities that released them (Great Lakes Science Advisory Board 1988).

Despite the importance of this topic, no inventory of accidents and spills involving toxic substances is maintained, assessed, and publicly reported in Canada.

The Management of Toxic Substances

Shifting ideas

The presence of toxic substances in the environment has been a serious issue for more than 30 years. In attempting to deal with it, decision-makers have faced the problem of assessing risk and making decisions under conditions of scientific uncertainty and widely differing public perceptions of the issue. Scientific uncertainty arises from the difficulty of measuring the effects of environmental exposure to extremely small quantities of these substances over long periods of time. Differing perceptions stem from the different interests and values that various individuals and sectors of society bring to bear in considering the issue. People do not approach these problems as neutral observers but as manufacturers, workers, environmental advocates, community members, consumers, and others with specific interests

that might be affected by decisions about toxic substances. They also approach them as individuals with varying degrees of concern about human health and the environment. Consequently, approaches to risk assessment and decision-making have continued to evolve not only in response to improvements in scientific understanding of these issues but also in response to changing perceptions among different segments of society.

Dealing with uncertainty — the precautionary principle

Recognition of the limits of human knowledge has brought a growing awareness of the need for caution in dealing with substances that have the potential to cause environmental harm. This idea is captured in the "precautionary principle." Perhaps the best-known expression of this concept is incorporated in Principle 15 of the Rio Declaration, released at the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, which states: "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

This definition has been broadly accepted, at least in part because of its reference to "cost-effective measures," which implies a willingness to undertake cost–benefit and comparative risk analyses as a basis for decision-making.

Some, however, feel that the adoption of measures to control toxic substances should not be limited by considerations of cost-effectiveness and advocate instead a *weight-of-evidence* criterion for action. Here, all data and information are synthesized, much as is done in courts of law, to develop the most informed assessment possible. If the weight of evidence indicates that a substance poses a serious threat to the environment or human health, proponents argue that this alone should be a sufficient basis for taking action to control it.

An additional dimension of the debate surrounding application of the precautionary principle relates to the concept of user/producer responsibility or *reverse onus*. This concept is clearly expressed in the following statement, made to the House of Commons Standing Committee on Environment and Sustainable Development by the then (Canadian) Chairman of the International Joint Commission, C. Lanthier: "For all chemicals for which environmental or health effects are reasonably suspected on the basis of weight of evidence, the onus should be on the proponent or producer to demonstrate safety rather than on governments to prove harm, before it is used, produced, or imported" (Standing Committee on Environment and Sustainable Development 1995).

CEPA currently requires manufacturers and importers to supply information about the toxicological and environmental effects of new commercial substances and the volumes proposed for manufacture or importation. However, this provision applies only to new substances; existing imported substances have fewer notification requirements, and existing domestic substances are exempt from notification.

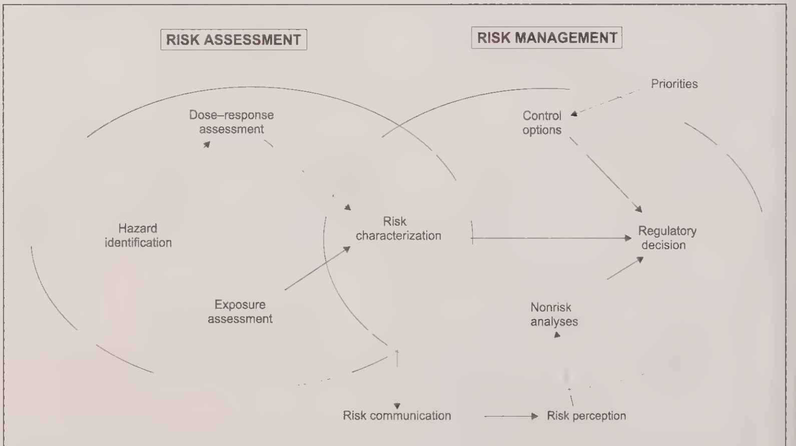
The government has accepted the concept of user/producer responsibility in its own CEPA reform proposals and has agreed to undertake further work to clarify to whom and how the concept would apply.

Dealing with risk

Much of the concern and debate over toxic substances stems from conflicting views on the degree of risk that they pose. Rigorous techniques of risk assessment that take into account both the probability of experiencing harm and the extent of that harm can help to resolve some of these differences. However, the quantitative risk estimates provided by these techniques are usually more useful in establishing the relative risk between competing courses of action than in determining an absolute level of risk for any given option. Comparative risk assessments are also only one input to decision-making. Social, political, cultural, and economic factors can play a role as well.

Risk assessment is complemented by risk management (Fig. 13.11). Together, these approaches have made a significant contribution to the control of toxic substances. Still, their role has been controversial, and the "illusion of surety" provided by the quantification of risk has been increasingly rejected by the general public. According to an assessment of the Canadian public's

Figure 13.11
The components of dealing with risk



Source: Modified from IJC (1995).

reaction to risk from toxic substances, this lack of trust has been the major barrier preventing the scientific community and the public from reaching consensus on priorities (Slovic 1993).

Increasingly, decision-makers are acknowledging that public concerns need to be included in the risk assessment process and in risk management decisions. Such an evolution is marked by a growing public involvement in technical decision-making.

Ecological risk assessment

Until recently, risk assessment as applied to toxic substances was the exclusive preserve of human health specialists: toxicologists, epidemiologists, and public health officers. The focus was primarily on the use of chemicals in food and pharmaceuticals, with some attention to environmental conditions affecting human health, such as drinking water quality, indoor air quality, air pollution in cities, and heavy metals in the environment. In the past decade, however, the field of risk assessment has expanded to include ecological risk assessment.

An ecosystem consists of all the organisms in an area, including humans, and the physical environment with which they interact. An ecosystem approach to toxic substances acknowledges the interconnectedness of all parts of the ecosystem and the complex interactions that occur in response to chemical, physical, and biological stresses (see Table 13.13). It recognizes the high degree of uncertainty that exists regarding human understanding of ecosystem processes, and it admits severe limitations in predicting outcomes.

Because of Canada's ecological diversity, it is exceedingly difficult to extrapolate conclusions from one ecosystem to another. Pathways, risks, exposure of wildlife and human populations, and clearance rates of contaminants from the environment can vary widely. Ecological risk assessment responds to this concern by being site-specific by design.

Ecological risk assessment extends the analysis of risk from a singular focus on humans to assessment of "safe" levels of exposure for other species in an ecosystem. In addition, it considers whether the interaction of contaminants lessens their combined effects (antagonism) or accentuates the degree of harm (synergism). It also takes into account the indirect effects of substances on ecosystems. Such effects could include the impacts on the food web of the loss or decline of a particular species or the impacts of substances such as chlorofluorocarbons (CFCs) or greenhouse gases on the ecosystem's physical life support system. To encompass such a diversity of considerations, ecological risk assessment requires a broad multidisciplinary approach involving human health specialists and a range of expertise drawn from the natural sciences. Incorporating this breadth of knowledge has been difficult.

The melding of the techniques of traditional risk assessment and management with ecological concepts and related information systems is in an early stage of development. However, the ecosystem approach is gradually transforming the interpretation and subsequent management of risk from toxic substances in both private and public sector initiatives. Its application to the assessment and management of contaminated sites, for example, is well advanced (see Gaudet 1994). The principles involved are also widely applied by site assessors and environmental auditors who advise financial institutions of the risk (or contingent liability) involved in certain investments. The concept of ecological risk shows up as well in CEPA, where a toxic substance is defined as one "that enters or may enter the environment in a quantity or concentration or under conditions that:

- have or may have an immediate or long-term harmful effect on the environment;

Table 13.13
Ecological risk assessment — an emerging field

Scope	Considers ecosystems as a whole, including humans
	Estimates the importance of all species and habitats in site characterization
	Considers a broad spectrum of stresses, including potential contaminants of concern and physical and biological stresses
	Considers exposure of a range of receptor species from multiple entry points of contaminants
	Considers both single-contaminant effects and synergistic and antagonistic effects
Methods	Selects representative sensitive species or biomarkers to act as indicators: • sentinel — a single species whose welfare acts as an early warning (canary in a coal mine approach) • keystone — a critical species, the linchpin of a food web or interdependent community
	Sets explicit benchmarks (assessment end points) that trigger action for protection of species
	Sets explicit measurement criteria (e.g., lethal concentration, reproductive success, developmental success)
	Considers both quantitative and qualitative aspects; uncertainty is carefully estimated
	Can be predictive (of future risks) or retrospective (assessing existing or past effects)
	Can be primarily observational (empirical) or theoretical (based on extensive modelling and research of cause–effect relationships)

- constitute or may constitute a danger to the environment on which human life depends; or
- constitute or may constitute a danger in Canada to human life or health."

Recognition of indirect effects is a relatively recent phenomenon and represents an important step in the evolution of the understanding of toxic substances. The emergence of ecological risk assessment thus reflects a pivotal change in society's perception of the toxic substances issue.

Responsibility for toxic substances

At the federal level, responsibility for policies and programs related to toxic substances is shared across 26 departments and agencies. Environment Canada holds overall responsibility for coordination, but many other departments are accountable for key areas. To name just a few examples, Transport Canada has responsibility for the transport of dangerous goods, the Pest Management Regulatory Agency, reporting to the Minister of Health, for the regulation of pesticides, the Atomic Energy Control Board for the regulation of the mining, use, and disposal of radioactive substances, and the Department of Indian Affairs and Northern Development for all aspects of toxic contaminants in the Yukon and Northwest Territories.

The provincial governments are also key players in the regulation of toxic substances, with the exception of a few areas that fall exclusively under federal jurisdiction, such as prescribed radioactive substances. Provincial responsibilities include such areas as the regulation of discharges to water and air, the regulation of waste disposal, the setting of standards, and licensing, monitoring, and enforcement.

In some cases, provincial and federal responsibilities overlap. The Canadian Council of Ministers of the Environment is pursuing the harmonization of federal and provincial environmental regulations and reviewing the distribution of responsibilities between the two orders of government. Similarly, regarding pesticide regulation, a federal–provincial–territorial committee exists in which cooperative activities are endorsed and encouraged.

Public concern and questions of legal liability have made toxic substances a central issue in the private sector as well. As a result, many companies, industries, and professional organizations have shown interest in control techniques, such as contaminated site verification and environmental auditing. The private sector is also exploring approaches that complement legislated measures. These approaches include market incentives, voluntary measures, and standardized international approaches to environmental management and auditing, such as the International Organization for Standardization's (ISO) new ISO 14000 standards (discussed below).

New approaches to dealing with toxic substances

In the last decade, life cycle assessment or management of commercial products, often called the "cradle-to-grave" approach, has become a familiar term. The premise of the approach is that every step in the industrial process that creates a product (all products, not just those involving toxic substances) must be assessed for its environmental impact. From raw material acquisition through bulk processing to secondary and final manufacture, inputs and outputs are scrutinized, not just for pollution (emissions, effluents, and wastes), but also for the energy costs of production and transportation, the use of water, and the impacts of extracting the resources.

Recycling remains important, particularly the "closed loop" approaches that keep materials circulating within the industrial process. Increasingly, however, the actual use of the product, its maintenance, and the ease with which it can be stabilized after withdrawal from service are being examined. The capture of escaped CFCs from automobile air conditioners during servicing is a familiar illustration of how the scope of recycling is being expanded. More attention is also being given to complex products, some of which contain metals (such as those used in batteries, television sets, computers, and appliances) or inorganic compounds (such as phosphorescent materials in video display units). In Germany, for example, the federal government recently required producers to take back television sets for disassembly, recycling, and orderly disposal of the laminates and composites used in their manufacture.

Although "first-generation" recycling of paper, cardboard, glass, and cans was relatively easy, the "second-generation" recycling that these more complex products require demands more sophisticated methods of retirement, treatment, and disposal. Recapturing small amounts of unfamiliar elements — like antimony, gallium, germanium, and selenium used in computers and industrial and commercial communications equipment — is an emerging challenge. The implications of releasing these trace elements into the environment, alone or in combination, are still largely unexplored.

As the sophistication of life cycle analysis of products increases, the true costs of the entire cycle — including environmental and social costs — become more apparent. To accommodate this broader concept of costs, techniques of full life cycle costing are emerging. These expand the scope of traditional life cycle costing to encompass all environmental and social costs, even those not directly assignable (or incorporated) into standard business accounting.

As a result of these kinds of analyses, some product lines and some raw material sources and production processes are being identified as inherently "unsustainable," particularly when viewed at an ecosystem or whole system level and over the complete cycle of product use. However, the changing approaches noted above reflect a shift in society's approach to the toxic substances issue. Although conventional "end-of-pipe" control solutions are still widely used, these are being supplemented by pollution prevention strategies, which in turn are being supplemented by fully proactive processes based on the concept of design for sustainability (see Virtual Elimination Task Force 1993; Keoleian and Menerey 1994).

Design for sustainability applies sophisticated life cycle principles to the full range of human activity, from mining and extraction through manufacturing, use, and, finally, recycling or disposal. It is a means of reducing stress on the environment while maintaining benefits in support of human well-being. It reflects a commitment to a process of continuous learning and adjustment.

Society's shift towards practical application of these principles is arguably of far greater importance than reductions of a given emission or of a given contaminant concentration in a particular compartment of the environment. Indeed, it may be the most fundamental and significant change that has occurred with respect to the management of toxic substances since the state of Canada's environment was last assessed in 1991.

Key initiatives

The federal Toxic Substances Management Policy

Released in June 1995, the Toxic Substances Management Policy explicitly adopts a preventive and precautionary approach to dealing with toxic substances that enter the environment and could harm the environment or human health. The policy provides a framework for making science-based decisions on the effective management of toxic substances that are of concern. The policy has two key management objectives:

- virtual elimination from the environment of persistent, bioaccumulative, toxic substances that result predominantly from human activity (Track 1 substances); and
- management of other toxic substances and substances of concern, throughout their entire life cycles, to prevent or minimize their release into the environment (Track 2 substances).

The policy applies to all federal regulatory and nonregulatory programs and provides a clear framework for the management of toxic substances. It will serve as the basis for the federal government's position on toxic substances issues in dealings with provincial and territorial governments, the private sector, and the international community.

The policy recognizes the need to apply a precautionary approach in identifying substances and implementing cost-effective measures to prevent environmental degradation. Naturally occurring substances, elements, and radionuclides are not candidates for Track 1 under the policy. However, when warranted, a natural substance that is used or released as a result of human activity may be targeted for reduction to naturally occurring levels under Track 2.

The Accelerated Reduction/Elimination of Toxics program

The ARET program is a joint industry and government initiative for reducing or eliminating emissions of toxic substances through voluntary measures. By December 1995, 270 organizations had agreed to take part. The sectoral associations represented by stakeholders in ARET include the chemical, steel, pulp and paper, mining, specialty chemical, electricity generation, and petroleum refining sectors. The members of these associations have participated in ARET at an average rate of 66%. The program is coordinated by Environment Canada, with guidance from a committee of representatives from industry, health and professional associations, and federal and provincial government departments.

Following a screening of some 2 000 candidate substances against the criteria of persistence, bioaccumulation, and toxicity, a list of 117 toxic substances or substance groups was targeted for action. At present, only 13 of these are regulated in any way. Fourteen of these substances or groups meet all three criteria. For these, ARET has set a target of virtual elimination of emissions, with a 90% reduction by the year 2000. For other ARET substances, a 50% reduction in emissions by 2000 has been targeted.

As of December 1995, 270 participating organizations had committed to a combined reduction in total emissions of over 21 000 t. This includes an average 36% reduction in emissions of reported substances that has already been achieved between the baseline year of 1988 and 1993, plus a commitment to a further 51% reduction by the year 2000, for a total average reduction of 69%. Also included in these targets is a 99% reduction in emissions of persistent, bioaccumulative, toxic substances (except PAHs) (ARET 1995b).

Many of these reductions are for substances found to be toxic under CEPA, for which there are no regulations at this time. The second ARET reporting cycle will be completed in the fall of 1996.

ISO 14000

The momentum towards global markets and international trade agreements has prompted a broad cross section of companies to develop and adopt voluntary operating standards. Their purpose has been both to develop some international criteria of quality control and to discourage government-imposed regulation. Much of this effort is funnelled through the ISO, based in Geneva, Switzerland, and represented in Canada by the Canadian Standards Association. ISO has 100 national standards bodies as members, representing countries that account for 95% of the world's industrial production.

Broad interest in principles of total quality management in the 1980s led to the establishment of ISO 9000, a form of corporate certification marking the achievement of a certain degree of management and quality control capacity. In view of the widespread acceptance of its ISO 9000 quality standards and the importance of the environmental agenda, the ISO is now developing a comprehensive set of environmental management standards. Known as ISO 14000, these standards will help companies better address growing environmental protection pressures, minimize legal and financial liabilities, reduce compliance costs, enhance stakeholder image, and gain competitive advantage (Biggs and Nestel 1995).

The ISO 14000 standard is, in fact, a series of standards and guidance documents that fall into two categories, the first aimed at environmental management systems and the second at product stewardship through life cycle analysis and design. Final versions of Category 1

standards are expected to be in place in 1996, and Category II in 1997. Canada has a particular interest in ISO 14000 because of its role in chairing and providing the secretariat for the Technical Committee.

ISO 14000 encourages the integration of quality and environmental management systems with a company's overall business management system. It is also being seriously considered for adoption under the North American Free Trade Agreement and the General Agreement on Tariffs and Trade as a mechanism to prevent the development of artificial trade barriers from country-specific environmental requirements.

The momentum for change in business cannot be attributed totally to a need to manage the production, containment, and disposal of toxic substances, but pollution prevention has been central to it. Public perceptions of risk related to toxic substances have encouraged changes to production processes, development of environmental audits, and site assessment for environmental liability. Energy savings, water use reduction, even habitat and wildlife protection have often been significant spin-offs. Good environmental management is increasingly being demonstrated as good for business.

The National Pollutant Release Inventory

The National Pollutant Release Inventory (NPRI) was established in 1993 to provide a national, publicly accessible inventory of pollutant releases and transfers in Canada. Like ARET, it was developed under the guidance of a multistakeholder advisory committee, which, in the case of the NPRI, included representatives from industry, environmental and labour organizations, and provincial and federal government departments.

A list of 178 substances was prepared for inclusion in the inventory for the 1993 reporting year, and a further 78 candidate substances were selected for possible inclusion in future years. Any company manufacturing or using any NPRI-listed substances in concentrations of 1% or more and in quantities of 10 t or more is required to file a report with Environment Canada identifying releases or transfers of those substances to air, land, or water.

A total of 1 466 facilities filed reports for the 1993 reporting year, identifying overall releases of 227 683 t for the year. Future reports will allow the tracking of data over time. For each substance, the NPRI data also indicate the relative quantities released to air, land, and water and the quantities released by each industry. The NPRI is the beginning of a database that will help define priority areas, measure progress, and support a variety of voluntary and regulatory initiatives in the future (NPRI 1995).

Assessing the role and effectiveness of society's options for controlling toxic substances

As the preceding examples illustrate, approaches to the control of toxic substances are becoming increasingly eclectic, with both government regulation and voluntary initiatives playing major roles. Market incentives that increase the direct costs of emissions and reward nonpolluters might also be added to the mix of control strategies. However, despite considerable debate about the relative merits of these options, no system is in place that can inform public discussion by providing an ongoing assessment of the role and effectiveness of each of these approaches.

CONCLUSION: TOWARDS THE NEXT NATIONAL ASSESSMENT OF THE TOXIC SUBSTANCES ISSUES

Signs of progress

Apart from the continuing progress that has been documented in the reduction of emissions of toxic substances in Canada, the major positive development since the release of the last national state of the environment report five years ago has been the evolution of concepts and approaches for managing toxic substances. Of particular importance has been the move towards sophisticated full-system, life cycle approaches to pollution control, supported by full-cost accounting techniques and rigorous systems of site assessment and environmental auditing. These concepts represent the emergence of a new concept of industrial ecology, and an overall pollution prevention strategy incorporating these ideas is now a central theme in federal government policy (Environment Canada 1995).

Continuing causes for concern

Despite mounting evidence that industrial processes are capable of significantly reducing the volume of toxic substances released to the environment, the overall use and release of toxic substances are nevertheless increasing steadily on a global scale. In response to market demand, production of organic compounds, metals, manufactured chemical goods, and their various by-products continues to grow. Inevitably, the output of toxic materials grows as well.

Further, globalization of the world's economy, although motivated by the potential for improving overall human well-being, is matched by the spread of a range of environmental impacts, many of them related to toxic substances. And just as there are inequities in the distribution of wealth, so too are there inequities in environmental degradation. Without the economic means to implement treatment and control measures, the world's poorest nations often receive the most exposure to toxic substances and thus live under the greatest risk.

To add a further dimension, the long time horizon required to account for the environmental impacts of toxic substances implies effects for both current and future generations. The release of toxic substances today may be threatening opportunities for future generations. Continuation of these trends has implications for global security, whether that security be measured in human or overall ecological terms (World Commission on Environment and Development 1987).

Lastly, the shift to a life cycle approach for the management of toxic substances also raises new difficulties: although such an approach promises a far more effective way

of reducing environmental damage, it also brings into question the very use of materials and products in the first place and puts the highly charged question of need versus want squarely in the spotlight.

These issues challenge the precautionary principle and the concept of sustainable development in a way that few others do. This is so because the argument is not one of extremes that pits "no evidence" against "absolute proof." Rather, there is difficulty in agreeing where the fine line should be drawn: at which point is there enough evidence to trigger a precautionary response, and how extensive should that response be? Without resolving these issues, the possibility of harmonizing economic development with environmental sustainability will become an ever more elusive goal.

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CHAPTER 14 BIODIVERSITY CHANGE

HIGHLIGHTS

Biodiversity means the variety of life. It is measured as the variety of species, the variety within species (genetic diversity), and the variety of ecosystems.

■

Canadian ecosystems include major portions of the world's Arctic (about 20% of all circumpolar Arctic land areas), forest (roughly 10%), and fresh water (about 9% of freshwater river runoff to the sea). Because it is a high-latitude country that emerged from glaciation fairly recently, Canada is relatively species poor: only 71 573 of the 1.5 million species known to science occur here.

■

Worldwide, wild ecosystems are undergoing unprecedented degradation, and species are becoming extinct at an alarmingly high rate. Human activities that put pressure on biodiversity include unsustainable agricultural practices, industrial releases of pollutants, excessive harvesting, and the introduction of new species into ecosystems.

■

Wild ecosystems, species, subspecies, and populations are disappearing before their ecological, economic, or medical value can be determined. There is a pressing global need for field research to study all the components of wild biodiversity, especially those most at risk of extinction, to avoid the loss of untold benefits to humanity.

■

In 1992, at the United Nations Conference on Environment and Development, the Framework Convention on Biological Diversity was signed. This international agreement to preserve biodiversity and to share equitably the costs and benefits of doing so has now been ratified by more than 115 countries. Canada has developed and is implementing its own action plan, the Canadian Biodiversity Strategy.

■

The creation of national networks of protected areas is a key strategy for conserving biodiversity around the world. Since 1990, protected areas in Canada have increased by about 15%, from 690 000 km^2 to almost 800 000 km^2, to include about 8% of the total land area of the country. Of Canada's 217 terrestrial ecoregions, 160 contain at least one protected area. In 1992, the federal, provincial, and territorial ministers responsible for environment, parks, and wildlife committed themselves to completing Canada's network of land-based protected areas by the year 2000. In recent years, there has been increasing recognition that protecting marine ecosystems is as important as protecting terrestrial ones.

■

The best hope for satisfying basic human economic needs without compromising biodiversity is the rigorous adoption of sustainable use policies and practices in all resource sectors.

■

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Introduction

At 9 215 430 km^2, Canada occupies close to 7% of the land area of the Earth, and 9% of all fresh water discharged into the world's oceans is from Canada (see Chapter 10). Canada also has the world's longest coastline, at 243 792 km, and the second largest continental shelf, with an area of 3.7 million square kilometres. The country is also characterized by a wide range of climates. These factors combine to provide a broad variety of ecosystems, life-forms, and species for aesthetic enjoyment and the expansion of human knowledge, but they also include a responsibility for the stewardship of the rich diversity. Yet, while there is a growing awareness of the complex and often fragile interdependence of ecological processes, these processes are under mounting pressure from human economic development. In many areas, from the fisheries to urban expansion to industrial growth, the balance between human activity and ecological sustainability is getting harder to find.

Biodiversity is one of the primary indicators of the planet's environmental health, and an understanding of the pressures on biodiversity is central to any strategy aimed at sustainability. The impact of human activities on the biodiversity of the planet is becoming better understood. Furthermore, it is no longer possible to examine the ecological impact of human activities in one area without considering that impact in other areas. The cutting of the Amazon rain forest, the industrial emissions of North America, the expansion of the Atlantic fishery, the growth of cities, even the use of road salt: all these are interconnected in ways that are becoming clearer.

The loss of biodiversity may mean the loss of untold benefits for humanity. A recent example of such benefits is the development of the cancer drug Taxol from the Pacific Yew found in Canada's coastal forests.

Activities that place pressure on biodiversity include the expansion of agriculture, pollution from industrial emissions, excessive commercial harvesting, and the introduction of new species into ecosystems. However, many positive initiatives are under way to inventory and preserve Canada's biodiversity and to monitor the effects of human activities upon it.

There is also ongoing research aimed at understanding the factors that make a species vulnerable to extinction. At present, there are over 250 species at various levels of risk in Canada. Many organizations, both public and private, are working to address the issues raised by the loss of biodiversity. Underlying these efforts is the principle of sustainability, which asserts the importance of balancing economic development with maintenance of the productive capacities of species and ecosystems.

This chapter explores the biodiversity of Canada within a global context and examines the human activities that are currently diminishing that diversity. It summarizes the collective strategies being implemented to counter such losses and concludes with some ideas about what directions our future efforts should take to better understand and conserve biodiversity and sustainably use Canada's biological resources.

What is biodiversity?

Biodiversity (short for biological diversity) refers to "the variability among living organisms from all sources including, among others, terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part" (Glowka et al. 1994; see also Federal–Provincial–Territorial Biodiversity Working Group 1995). It includes diversity within species, between species, of ecosystems, and of ecological processes.

An ecosystem is a dynamic system composed of a more or less definable space, its physical characteristics, the living organisms that inhabit it, and the ongoing processes by which they interact with their environment and each other. Understanding of the planet as an integrated system increased substantially in the 1970s, when the British scientist James Lovelock published *Gaia: a new look at life on Earth* (Lovelock 1979). In it, he advanced the somewhat controversial idea that the Earth is a single, planetary organism that sustains itself by means of a self-regulating system in which living and nonliving components interact to maintain dynamic stability.

Ecosystem diversity refers to the number, variety, and extent of ecosystems either globally or within a given geographic area. Ecosystems occur on many different scales. The Earth itself constitutes a global ecosystem or ecosphere. The ecosphere, in turn, consists of a multitude of smaller ecosystems, some of them contiguous, some interlocking, some nested one within another. All are interdependent, right down to the microsystem in the gut of a gnat. Ecosystems also include the social, cultural, and economic activities through which humans participate in the ecosystems that they inhabit. Human settlements may be viewed as specialized ecosystems.

Species diversity refers to the variety of species on Earth or within a given area or ecosystem. About 1.5 million species of organisms have been scientifically described to date (Table 14.1), but the total number is estimated to be much greater, ranging from 5 million to 100 million (Groombridge 1992). Most of the undiscovered or unnamed species are microorganisms, nonvascular plants, and invertebrate animals. The majority probably inhabit tropical rain forests. In Canada, 71 573 species have been reported, but it is estimated that another roughly 66 600 species, excluding viruses, remain to be recorded (Mosquin et al. 1995; see also Chapter 10).

Genetic diversity refers to the extent of heritable variation among members and populations of a given species. The physical characteristics of any organism are determined by the particular combination of genes that it has inherited from its forebears. The favouring of certain characteristics, whether by natural selection or (in the case of domesticated species) by selective breeding, influences the frequency of particular genetic combinations and may result, over generations, in the evolution of distinctive races, subspecies, and species.

A high degree of diversity within the gene pool of a species is one of the best assurances that the species will be able to adapt to changing conditions and thus survive and give rise to successful offspring. The diversity of the gene is the "library of life" — the record of those organisms that have been successful under a range of conditions in the past and which may be necessary for survival under future conditions.

Why biodiversity is essential

Diversity of ecosystems, species, and genetic material is critical to the integrity of the planetary ecosystem. Maintaining diversity helps ensure that the Earth will continue to perform the natural ecological processes upon which all life depends (Boxes 14.1 and 14.2).

Biodiversity might still be a topic of largely academic interest but for one major factor — ecosystems are undergoing unprecedented degradation, and species are becoming extinct at an alarmingly high rate. The current rate of extinctions could be 1 000–10 000 times the rate of extinctions of any previous period in the Earth's history. Estimates are that as many as two-thirds of all species now living may face extinction within the next century (Raven 1994). In addition to the loss of wild species, the genetic diversity represented in the variety of the world's food supply has also become eroded.

Humans have not managed their activities in ways that ensure that the Earth's ecosystems and species will be maintained into the future. Generally speaking, ecosystems have been exploited primarily to support the expansion of the human population (food, habitat, industrial uses). While the human population of the world has more than doubled since 1950, human consumption of resources has increased 10-fold — to the point where Vitousek et al. (1986) proposed that perhaps nearly 40% of potential terrestrial net primary productivity of the Earth is now appropriated by humans.

Never before has a single species attained a position of such dominance that it could threaten the sustainability of the whole global ecosystem. By harvesting entire populations of flora and fauna, by radically altering major habitat zones, and by influencing the functioning of fundamental ecological processes, humans are precipitating a crisis in global biodiversity, which in turn has the potential to threaten their own future survival.

In this period of radical environmental change, it is highly probable that species of unknown ecological importance, as well as untold economic and medical potential, are disappearing before their existence has been confirmed. Clearly, Canada and the world will eventually suffer a reduction in the benefits of biodiversity if steps are not taken to conserve it.

Table 14.1
Number of species (known and estimated) in most major groups of organisms, Canada and the world

	No. of living species			
	Canada		The world	
Major category of organisms	Known	Estimated	Known	Estimated[a]
Viruses	200	150 000	5 000	500 000
Bacteria	2 400	23 200	4 000	400 000
Fungi	11 310	16 500	70 000	1 000 000
Protozoans	1 000	1 000	40 000	200 000
Algae	5 303	7 300	40 000	200 000
Plants (embryophytes[b])	4 120	4 250	250 000	300 000
Molluscs	1 500	1 635	70 000	200 000
Crustaceans	3 139	4 550	40 000	150 000
Arachnids	3 275	11 006	75 000	750 000
Insects	29 913	54 566	950 000	8 000 000
Vertebrates	1 795	2 310	45 000	50 000

[a] Estimated numbers of species for the world vary greatly for some groups of organisms; those used in the table are the "working figure" cited in Groombridge (1992).
[b] The "higher" plants, or vascular plants.

Source: For Canada, Mosquin et al. (1995); for the world, Groombridge (1992).

The State of Biodiversity

Biodiversity and evolution

During the course of evolution, there have been immense fluctuations in biodiversity. At least five times, major episodes of extinction have cut species numbers by more than 50%. It is estimated that more than 90% of all the species that ever existed are extinct (Myers 1984). Most were lost in spasms of global catastrophe. For example, many scientists believe that the impact of a comet striking the Earth triggered the sudden mass extinction of the dinosaurs some 67 million years ago (Hildebrand 1993).

Perhaps the most significant point to be made about the major extinctions is that each was followed by a period of accelerated evolution, during which the number of species appears to have rebounded to equal or surpass previous levels. This process requires millions of years to occur. During the last 200 million years, in particular, the overall trend in species diversity has been upwards. It is likely that more species have coexisted on Earth during the last million years than ever before.

The state of ecosystem diversity

Figure 14.1 depicts vegetation units (biomes) around the world. On this map, the vegetation units roughly correspond to major global ecosystems and represent biodiversity at its broadest scale.

Because of its size (it is the second largest country in the world by area) and because it consists chiefly of polar and

temperate ecosystems (Fig. 14.1; see also map of ecozones of Canada in the Introduction to Part II of the report), Canada has an important role as steward of major portions of the world's tundra, temperate forest, and aquatic ecosystems. Canada's stewardship also extends to smaller expanses of grassland and cold-winter desert ecosystems (Fig. 14.1) that, by virtue of their limited size and relative scarcity in the higher latitudes, may be in need of even more protection than other ecosystems.

Arctic diversity

Arctic ecosystems occupy about 10% of the world's land area, and Canada has about 20% of all circumpolar Arctic land areas (see Chapter 9). Arctic regions sustain a wealth of lichens and plant species that thrive in the postglacial landscape. A major factor affecting species diversity in Arctic Canada is the seasonally high productivity of the marine ecosystem, which attracts large numbers of seabirds and other marine animals to these waters (Department of Canadian Heritage 1995).

Although seemingly unspoiled, the Arctic regions are not immune to environmental stresses. Atmospheric and oceanic currents carry pollutants to the polar regions, where potentially harmful accumulations of toxic materials have been found in the food chain up to marine mammals (such as Polar Bears), birds, and people. Over time, such stressors may place certain species at risk of decline and possible extinction. The Arctic is perhaps one of the few ecosystems for which it is still possible to plan for biodiversity conservation before any major degradation occurs.

Forest diversity

Close to 10% of the world's forests, and a much greater percentage of all boreal forests, grow in Canada. They represent a valuable economic resource and a vital habitat for organisms that inhabit the temperate domain.

Forest ecosystems perform a wide array of vital ecological tasks. They filter and purify the atmosphere. They provide a living substrate for the maintenance and evolution of complex communities of organisms, from detritus-consuming bacteria and shade-loving herbs to highly specialized insects, mites, and birds. They protect watersheds against soil erosion, and they moderate the impact of climatic extremes of temperature, wind, and precipitation. Living trees contribute oxygen to the atmosphere, whereas the breakdown of their leaves and other organic debris sustains rich communities of microorganisms and invertebrate animals that contribute to the formation of fertile soil.

At the global level, forest biodiversity is being seriously compromised by the continued swift loss of tropical rain forests. In Canada, forest biodiversity is threatened by reductions in the extent of forest types such as Carolinian species of southern Ontario and by the loss of old-growth forests on the west coast, which provide habitat for specialized species such as the Spotted Owl. Fragmentation of forested areas to the point where they cannot support species that rely on large contiguous forest habitat is also a concern.

Box 14.1
Case study: biodiversity in the upper Bay of Fundy

The complex global role of biodiversity is perhaps best demonstrated by the interaction of spaces and species on a local scale. The Bay of Fundy provides a good example. The lower portion of the bay is an extremely productive marine ecosystem, rich in nutrients and species. Upwelling currents, caused by the influx of tidewater, stir up nutrients in the water and support enormous populations of phytoplankton. Besides producing oxygen, these microscopic plants provide an abundant food source for zooplankton, which, in turn, are food for many predators: vast schools of herring that in turn are fed upon by larger fish, seals, and porpoises; wintering populations of seabirds; and even a sizable portion of the North Atlantic population of the endangered Right Whale.

The ecosystem that occupies the upper part of the bay is very different. Here, the erosive force of the highest tides in the world fills the water with so much suspended silt that phytoplankton cannot grow. Where the shoreline is low, centuries of tidal deposition have resulted in the creation of vast expanses of fertile salt marsh. Sunlight and nutrients enable the salt-marsh ecosystem to produce thousands of tonnes of grass every summer. In winter, tide-driven ice shears off the grass and pulverizes it. The resulting organic debris is subsequently consumed by bacteria and a wide range of detritus-eating invertebrates (Gordon and Desplanque 1983). In this way, enormous quantities of energy are exported from the marshes to the adjacent marine ecosystem.

Subsequently, this product may reach more distant parts of the ecosphere as well. One of the principal consumers of salt-marsh debris is Corophium volutator, *a tiny mud shrimp that occurs by the tens of thousands per square metre on the intertidal mudflats of the upper Bay of Fundy but at no other location in North America. This concentration of crustaceans plays an essential role in the life cycle of the Semipalmated Sandpiper, which preys preferentially on the mud shrimp (Hicklin and Smith 1984).*

Every summer, between 1 and 2 million of these sparrow-sized shorebirds leave their nesting grounds in the Arctic and converge on the shores of Shepody Bay and the Minas Basin. Here, during 10–12 days of intense feeding, each bird doubles its weight, taking on enough fat reserves to fuel a nonstop, 72-hour flight to the species' winter habitat along the coast of Surinam, in South America (Gilliland 1992). The encounter between birds and shrimp at this particular intersection of time and space is critical to the success of the sandpipers' migration and illustrates how conditions in one highly specialized local ecosystem can influence events in other ecosystems thousands of kilometres away.

Box 14.2
The importance of biodiversity

Conserving biodiversity, including using biological resources in a sustainable manner, is an essential part of Canada's effort to achieve sustainable development. The diversity of life on this planet supports vital ecological processes. Together with the development of mineral, fossil fuel, and other resources, it provides the building blocks of economic activity. The Earth's ecosystems, species, and genetic resources also support human society in other ways, both spiritually and culturally.

Life-sustaining services

Ecosystems are composed of air, water, land, and biota. Each organism performs a specialized role within the ecosystem. Ecosystems provide ecological services, such as the conversion of solar energy into carbohydrates and protein, oxygen production, water purification, and climate moderation. Other ecological services include producing the soil needed for farming and removal of greenhouse gases from the air. Although human health depends on these ecological services, their value has never been fully appreciated by society.

Employment

The diversity of the Earth's life-forms provides a wide array of options for satisfying human needs, including the need for gainful employment. Millions of people who work in agriculture, fishing, and forestry rely on biological resources to earn their living. Ecotourism and outdoor recreational activities, increasingly important parts of the Canadian economy, also depend on biological resources, as do pharmaceutical and biotechnological research and development. Many indigenous communities, particularly in the North, depend on the sustainable harvesting of biological resources to provide a large portion of their food and income.

Spiritual inspiration and cultural identity

For many Canadians, the diversity of spaces and species in this country is a source of emotional, artistic, and spiritual inspiration and cultural identity. Indigenous peoples have developed an intimate cultural relationship with nature. Moreover, Canadian identity has been shaped in part by the beauty of the natural landscapes: the rugged coast of Newfoundland, the Gulf of St. Lawrence, the Great Lakes, the Canadian Shield, the prairie grasslands, the west coast forests, and the Arctic. This wild, elemental beauty — captured by painters, writers, and musicians — defines Canada to its citizens and to the world. Many Canadians believe that each species has its own intrinsic value, regardless of its value to humanity, and that human society must be built on respect for the life around them. They believe that biodiversity should be conserved for its own sake, regardless of its economic or other value.

Insurance for the future

Maintaining the Earth's biodiversity and using biological resources sustainably mean keeping open our options for responding to unforeseen and changing environmental conditions. Maintaining our potential as a country to be creative, productive, and competitive will also provide us with opportunities for discovering and developing new foods, drugs, and industrial products. For example, many of our native plant species must endure both cold winters and hot summers. These plants may possess genetic material that could be used to develop agricultural crops that can withstand greater temperature ranges. Failing to conserve biodiversity puts future options, flexibility, and economic opportunities at risk and passes enormous costs on to future generations. Conserving biodiversity is an investment in the future and makes good business sense.

Source: Federal–Provincial–Territorial Biodiversity Working Group (1995)

Grassland diversity

Although most have been dramatically altered by human activities, grassland biomes represent about 20% of the Earth's land area (see Fig. 14.1). At the time of European settlement, prairie grassland ecosystems covered about 500 000 km^2 of western Canada, sustaining a rich and highly specialized floral and faunal community. Since then, more than 80% of Canada's grasslands have been converted to agricultural use, and their original diversity has been altered profoundly, such that only about 1% of Canada today remains as grassland ecosystems. An important part of the conservation challenge is to protect and enhance native prairie biodiversity within the modern agricultural landscape.

Wetland diversity

Canada has 24% of the world's wetlands and a much higher proportion of its boreal fens and bogs. Wetlands around the world are among the most varied and biologically productive of all ecosystems. They support a great diversity of plants and provide ideal breeding and feeding sites for many kinds of invertebrates, fish, amphibians, and waterfowl. Other important ecological functions of wetlands include water retention and purification and flood and erosion control. Removal of wetlands (for agriculture or urban development) eliminates habitat for wetland-dependent wildlife species and can seriously disrupt the seasonal supply of fresh water over large areas.

Freshwater diversity

Canadian river runoff to the sea is about 9% of the world's total freshwater runoff, and freshwater ecosystems cover more than 7% of Canada's surface area. Such a quantity of surface water has a significant climatic effect, cooling adjacent areas in summer and moderating winter cold.

Canada's freshwater ecosystems sustain approximately 180 fish species, a rich variety of aquatic plants, and many invertebrates, including some groups of arthropods that appear to achieve their greatest diversity in temperate latitudes.

Pollution by industrial and urban wastes is a significant threat to the quality of freshwater habitats, whether from point source release of effluents from industry and urban settlements or from airborne pollutants that fall as wet (e.g., acid rain) or dry deposition.

Marine diversity
The diversity of marine ecosystems is only beginning to be understood and measured. Globally, the range of marine ecosystems is known at the broadest level only.

Canada has five major marine ecozones (see Fig. II.2, Introduction to Part II of this report) spread over 5 million square kilometres of ocean (see also Marine Environmental Quality Advisory Group 1994). They include some of the most productive marine ecosystems in the northern hemisphere. The total marine food web contains thousands of different kinds of organisms.

Threats to Canada's marine ecosystems include overfishing, by-catch, the destruction of habitat, and pollution, as well as possible global environmental changes, such as alterations in climate, temperature, and ocean currents. The thinning of the global ozone layer places phytoplankton, the biological foundation of the marine ecosystem, at risk.

The state of species diversity

Knowledge of species diversity is both extensive and incomplete (see Table 14.1). Taxonomic inventories are steadily growing — for example, between 1979 and 1988, on average, about 11 700 new species each year were listed in the global zoological record (Groombridge 1992). Nonetheless, it is likely that up to 85% of the world's species remain to be discovered and scientifically described. Factors to consider when assessing species diversity include species distribution and richness, endemism, and risk of extinction.

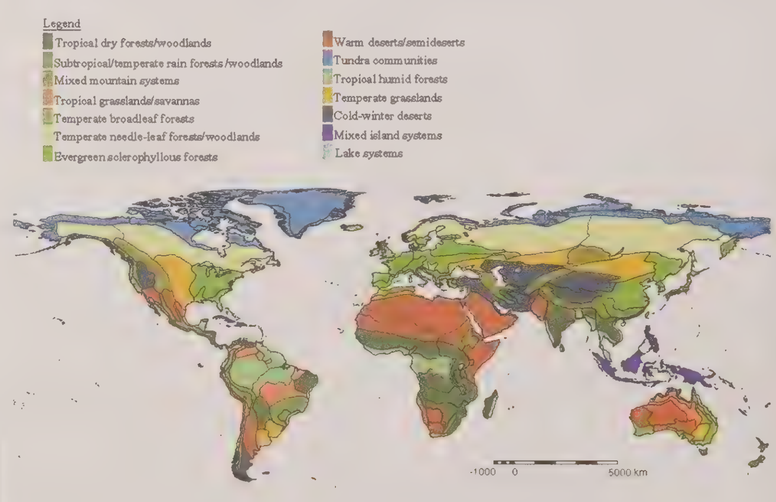
Distribution and richness
Species richness is indicated by the number of species within a group or within an area. For example, the class Insecta, with 950 000 known species worldwide, is far more species rich than the class Mammalia, with 4 327 recognized species (Groombridge 1992). Brazil, a large, species-rich country, has close to 55 000 known species of flowering plants; Canada, a larger country with less species richness, has about 2 980 known species of native flowering plants (Mosquin et al. 1995; see also Chapter 10). The diversity of higher taxa is greater in marine ecosystems than in terrestrial ecosystems.

Species are not distributed evenly among the world's ecosystems. Numbers of species in most, but not all, taxonomic groups tend to decrease from equatorial to polar latitudes. Latin America (Mexico through to the southern tip of South America) alone boasts over 85 000 higher plant species (i.e., flowering plants, conifers and kin, and ferns and their allies), whereas the United States and Canada have only 17 000 (Groombridge 1992); only 4 039 species of higher plants occur in Canada, including about 930 introduced flowering plants (Mosquin et al. 1995). The so-called latitude gradient illustrates a correlation between species diversity and climate.

The fact that Canada has relatively fewer species than do other nations does not diminish the importance of the species that are found here. Northern latitude and recent emergence from the last ice age (the Wisconsin glaciation) are two factors that limit species diversity. The effect of these factors is evident in Figure 14.2, which shows distributional trends in species richness as reflected by the ranges of higher vertebrates in Canada. Generally, the latitude gradient applies. Thus, the Arctic Cordillera and Northern Arctic ecozones have the fewest resident species of birds and mammals and no reptiles or amphibians at all. Richness increases in the Southern Arctic ecozone and the three Taiga and three Boreal ecozones and reaches its highest level in the Mixedwood Plains ecozone and the south-central portion of the Montane Cordillera ecozone.

Endemism
The term endemic refers to species found only in a specific geographic area. Eighteen known terrestrial locations around the globe are particularly rich in endemic species (Groombridge 1992). Yet these

Figure 14.1
Biomes of the world



Source: Udvardy (1975).

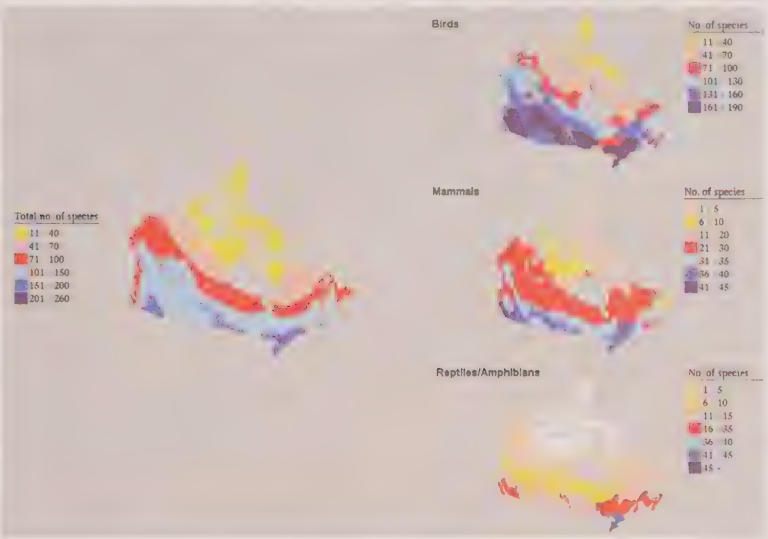
regions cover only 0.3% of the Earth's land area. They reflect combinations of geological, climatic, biogeographic, and ecological factors that have favoured the evolution of diversity and specialization. Globally, one of the principal threats to species diversity is the fact that many of the areas that are richest in endemics are also prime targets for intensive economic development.

Islands, largely because of their isolation and limited size, tend to have less species richness and more endemism than equivalent continental areas (Groombridge 1992). Thus, the Queen Charlotte Islands support only about 80 resident vertebrate species but provide some good examples of island endemism. At least two fish, the Giant Stickleback and the Charlotte Unarmoured Stickleback, occur nowhere else in the world. The *pealei* subspecies of the Peregrine Falcon is endemic to these islands, as was Dawson's Caribou, an extinct subspecies of the Woodland Caribou.

Known endemic species elsewhere in Canada include a mammal (the Vancouver Island Marmot), several fish species (e.g., the Acadian Whitefish, Copper Redhorse, and Enos Lake Stickleback), and at least 93 vascular plants representing 24 different families (see, for example, Box 14.3).

To a large degree, the distribution of endemic plant species in Canada (Fig. 14.3) reflects the extent and recency of glaciation. The several endemics that occur in rugged locations such as the Arctic or the perimeter of the Gulf of St. Lawrence are likely pioneer species, able to colonize harsh habitats (Parks Canada 1986). Others are concentrated in those ecozones of the Yukon (with 28 endemic plants) and British Columbia (47 endemics) that are believed to have escaped the severe scouring action of the Wisconsin glaciation. The distribution of endemic plants by ecozone is indicated in Table 14.2.

Figure 14.2
Estimated species richness in terrestrial vertebrates in Canada



Source: Natural Resources Canada and Environment Canada.

Box 14.3
Endemic species of the Athabasca sand dunes

On the south shore of Lake Athabasca, in the northwest corner of Saskatchewan, there is a highly unusual landscape. Large sand dunes, shaped and shifted by the wind, shelter an almost desert-like ecosystem at the northwestern edge of the Boreal Shield ecozone. This ecosystem houses one of the most concentrated communities of endemic plant species anywhere in Canada. In all, 10 unique plant species — four species of willow, one species of the everlasting family, one grass, one rock cress, one sedge, one tansy, and one yarrow — occur among these sandy hills and nowhere else on Earth. All are thought to have evolved from more widespread forebears in the few thousand years that have elapsed since the retreat of the last episode of glaciation. Two of them, Tyrrell's Willow and Athabasca Thrift (everlasting family), have been officially designated as threatened. Any major disturbance to the fragile dune structure, such as large-scale removal of sand or unrestricted use of all-terrain vehicles, could put the entire ecosystem, including all 10 endemic species, at risk.

Risk of extinction

Another element in assessing biodiversity is determining when and what species are at risk of extinction. Neither time nor resources are available to inventory and monitor all known species, let alone make informed judgements about the millions yet to be described. Nevertheless, it is important to review the status of as many individual species as possible, as an indicator of the overall status of species diversity. Internationally, this responsibility has been undertaken by the World Conservation Union (IUCN), which publishes periodic "Red Lists" of threatened species. Globally, the 1994 list indicates 5 929 threatened species of animals, 3 175 of which are vertebrates (IUCN 1993). Of particular concern for conservation efforts is the fact that some 65% of the vertebrate species and 78% of the invertebrate species listed are endemic to single countries.

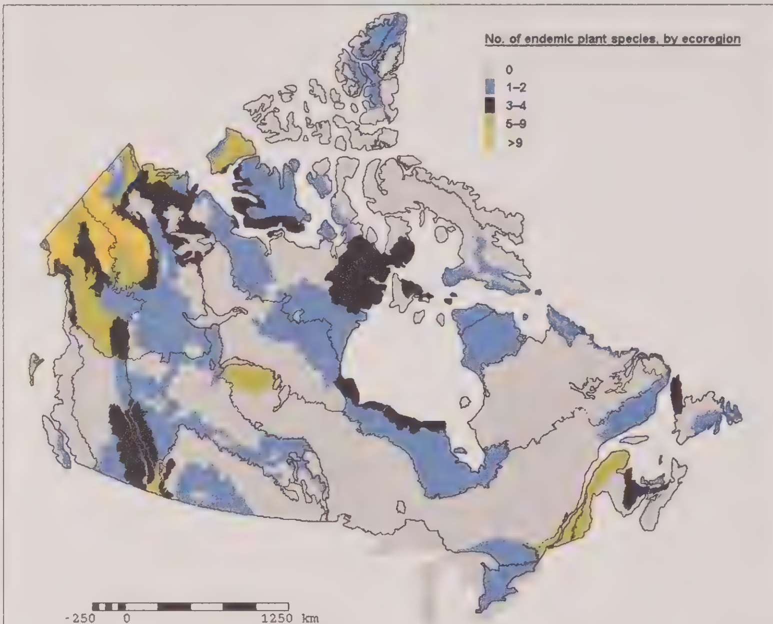
In Canada, a similar task is performed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Since 1978, COSEWIC has reviewed the status of 352 species, subspecies, or discrete populations of vertebrates and higher

plants in Canada. The COSEWIC risk categories include:

- *extinct*: no longer exists;
- *extirpated*: no longer existing in the wild in Canada, but occurring elsewhere;
- *endangered*: facing imminent extirpation or extinction;
- *threatened*: likely to become endangered if limiting factors are not reversed; and
- *vulnerable*: of special concern because of characteristics that make it particularly sensitive to human activities or natural events.

Table 14.3 summarizes current COSEWIC designations of endangered, threatened, and vulnerable species, subspecies, and populations, whereas Figure 14.4 presents trends in assigned designations since the inception of the program.

Figure 14.3
Distribution of known endemic plant species, by ecoregion



Source: State of the Environment Directorate, Environment Canada, based on Haber (1994).

Agents of Biodiversity Change

Environmental influences

Despite the appearance of permanence, change is an inherent characteristic of ecosystems. Rivers and glaciers erode old ecosystems and carve new ones. Alterations in atmospheric and ocean currents induce climatic changes — warming, cooling, precipitation, drought — that transform the ecosystem characteristics and lead to a decline in certain habitats and species and enable the emergence and dominance of others.

Other agents of change include volcanoes, fire, wind, insects, and disease. Volcanic eruptions, while rapid and powerful in the short term, create fertile new landscapes for repopulation in the long term; large eruptions can change climatic patterns. Fire, insects, and windstorms are common natural agents of change in forested ecosystems (Waring and Schlesinger 1985). Fire, while it can transform large areas of forest, is an essential ecological process that produces diversity in tree ages, promotes the emergence of colonizing species, and enables the propagation of many species, such as Lodgepole Pine.

Prior to extensive human settlement, fire also played a significant role in maintaining diversity in prairie ecosystems.

Human activity

One of the chief agents of change in biodiversity demands special mention: human activity.

The extinction of species has long been a by-product of human activity. Ever since the Stone Age, hunting has been a causal factor in the extinction of animal species. Often, however, extinctions have been incidental. Whenever human populations have migrated into new territories, they have brought with them pets, plants, pests, and livestock, many of which have preyed upon native species, parasitized them, spread diseases among them, or competed successfully against them for food, shelter, and reproductive dominance. Table 14.4 shows some modern examples of such extinctions in Canada.

Although species exist for widely varying amounts of time, the prehistoric rate of extinctions as represented in the fossil record is widely believed to have been much slower than that in the last several hundred years. Also, most historical extinctions appear to coincide with the presence of human beings, although the causal links are not always easy to make. Diamond (1987) identified the following major threats to birds at risk (i.e., classified as "endangered" on the international "Red List") around the world:

- Nearly two-thirds of these bird species are threatened by loss of habitat — habitat destroyed through the taking over of land for housing, expanding industries, the extraction of raw materials, and agriculture; habitat altered through forestry operations; and habitat lost as a result of wetland drainage.
- In second place, at roughly two-fifths,[1] comes direct persecution by humans in the form of hunting, the collecting of

1. Many birds are influenced by more than one threat, so the proportions do not add to 100%.

birds and their eggs, including illegal trapping for the cage-bird trade, and disturbances caused at breeding grounds by sport and leisure activities.

- The third major threat, at about one-fifth, comes from competition from introduced species — alien plant introductions can lead to replacement of the original vegetation, alien mammal introductions can lead to high levels of predation, and alien bird introductions can lead to predation, competition, and, in some cases, hybridization.
- Finally, pollution and incidental takes from fishery operations add to the toll.

Habitat alteration

Europeans began settling in Canada in the early 17th century. Since then, many of the presettlement ecosystems have been significantly altered (Fig. 14.5). Broadly speaking, most changes at the ecosystem level can be attributed to settlement, cultivation, industrial and domestic pollution, or harvesting of commercially valuable life-forms, such as trees and fish.

Forests

Significant portions of the forested lands that existed in Canada in the early 17th century have been cleared for agriculture or settlement, including over 3 million hectares in the Atlantic Maritime ecozone and more than 7 million hectares in the Mixedwood Plains ecozone. In some regions, most notably southern Ontario and Quebec, the historic forest cover has been cleared for urbanization and agricultural purposes. About 90% of the Carolinian forest in Canada has been cleared (Mosquin et al. 1995), and the remaining forest is fragmented, severely putting at risk wildlife species that require continuous forest cover.

Notable among human activities that impact forest ecosystems within Canada is management for timber production, including harvesting and suppression of wildfires and insect infestations. Because of the variety of forest site conditions in Canada, three broad categories of silvicultural systems are used: selection, shelterwood, and clear-cut systems.

Clear-cutting is the most common method of harvesting in Canada (Natural Resources Canada 1995). Clear-cutting accounts for over 99% of all harvest along the B.C. coast, over 90% of the harvest within the country's boreal forest, and 80–85% of all harvest within the Maritimes and southern Ontario and Quebec (see Chapter 11). The environmental effects of clear-cutting vary considerably, depending on site conditions, structure and composition of the forest, the spatial and temporal distribution of harvesting, and the methods used to access and log the forest (Keenan and Kimmins 1993). The ecological implications of this practice continue to be the subject of much public debate.

Grasslands

Most of the prairie ecosystems of Canada, including 80% of the aspen parkland and shortgrass prairie and 99% of the tallgrass prairie, have been altered through agricultural land use, particularly conversion to cropland. Much of the remainder has been appropriated for transportation and urban development. Relatively undisturbed rangeland exists in some abundance and offers hope that species can be reestablished. Bison no longer freely roam the plains. The Black-footed Ferret has been

Table 14.2
Number of known endemic plant species in Canada, by ecozone

Ecozones	No. of species
Arctic Cordillera	2
Northern Arctic	10
Southern Arctic	17
Taiga Plains	12
Taiga Shield	2
Boreal Shield	19
Atlantic Maritime	10
Mixedwood Plains	7
Boreal Plains	5
Prairies	5
Taiga Cordillera	22
Boreal Cordillera	25
Pacific Maritime	9
Montane Cordillera	15
Hudson Plains	4

Source: State of the Environment Directorate, Environment Canada, based on Haber (1994).

Table 14.3
Summary of endangered, threatened, and vulnerable species, subspecies, and populations in Canada

Group	No. of species		
	Endangered	Threatened	Vulnerable
Mammals	12	8	23
Birds	15	7	24
Reptiles/amphibians	4	3	7
Fish	3	12	38
Plants	23	33	31
Total	57	63	123

Source: Adapted from COSEWIC (1995).

extirpated from its Canadian range. Threatened raptors, such as the Burrowing Owl and Ferruginous Hawk, have lost nest sites to agricultural activities and may be poisoned by prey contaminated with pesticides (Burnett et al. 1989).

Agricultural areas

The impacts of agriculture on biodiversity are many and varied. Irrigation, to permit food production in arid areas, may deplete aquifers faster than they can be replenished by the accumulation of groundwater. Intensive mechanical cultivation of topsoil often leaves it vulnerable to wind and water erosion, which in turn reduces soil fertility and the diversity of microfauna (e.g., bacteria, mites, and worms) that promote decomposition and good soil structure. Monoculture cropping can lead to dramatic increases in the population of pests and in plant diseases. Intensive farming, with large amounts of chemical pesticides and fertilizer applied to monocultured crops, will alter native biodiversity to a greater degree than lower-impact land uses, such as grazing. Many of the impacts of certain agricultural practices on biodiversity may remain undetected for years. Such was the case with dichlorodiphenyltrichloroethane (DDT) and its now-known impact on food webs.

Wetlands

As with grasslands, a high percentage of wetland ecosystems in southern Canada have been converted to croplands and lands for other uses. Since European settlement, losses or severe degradation of wetlands have included 70% of Pacific estuary marshes, including 80% in the Fraser River delta; 70% of central Prairies potholes; 68% of southern Ontario wetlands; and 65% of Atlantic coastal salt marshes (Rubec 1994). Drainage for agriculture has accounted for about 85% of these losses, urbanization and industrial development have been cited for 9%, and the remainder has largely been attributed to leisure and recreational property expansion and large flooded areas for hydroelectric reservoirs and water level management. To a degree, wetland conservation and restoration programs have offset some of these losses, although managed wetland areas often lack the richness of ecological process and species diversity that characterizes undisturbed natural wetlands (Mosquin et al. 1995).

Aquatic ecosystems

Human activity has had a variety of impacts on aquatic ecosystems. Among these are overfishing, eutrophication (nutrient enrichment), contaminant loadings, structural changes to habitat, and introductions of exotic species (Ryder and Scott 1994). Often these act in concert with the effect of deterring growth, production, or reproduction of fishes and other biota within the ecosystem. These stresses tend to drive aquatic ecosystems to less resilient, less complex, similar states. In short, the composition of aquatic ecosystems and natural ecological processes are compromised.

Hunting and harvesting

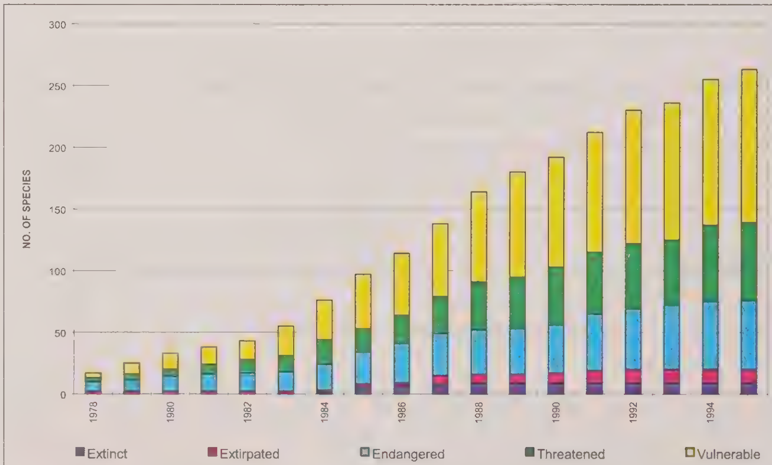
Unregulated hunting, trapping, and collecting can seriously stress wildlife populations. Commercial hunting, for example, caused the extinction of the Great Auk and Passenger Pigeon and the near-extinction of the Eskimo Curlew. Intensive trapping extirpated the Sea Otter from Canadian waters by 1929, and trapping, along with habitat fragmentation, has seriously reduced populations of other furbearers, such as the Newfoundland Marten.

In recent decades, extinctions and extirpations from harvesting of wildlife have declined because of improved knowledge of the threats to species and because of changing policies and legislation, combined with better management and enforcement. Improved management has significantly increased numbers of some ungulate species, such as North American Elk, bison, and Pronghorn.

Harvesting can put plants as well as animals at risk. The endangered Eastern Prickly Pear Cactus is at risk from amateur collectors. Furthermore, many once-common native wild species, while not necessarily at risk, have had their numbers greatly reduced by a combination of habitat loss and commercial harvesting. For example, Wild Leek, which requires a long time to mature and reproduce, may have difficulty recovering following excessive harvesting.

Figure 14.4

Cumulative change in numbers, by category of risk designation, of all species, subspecies, and populations evaluated by COSEWIC



Source: COSEWIC Secretariat, Canadian Wildlife Service, Environment Canada.

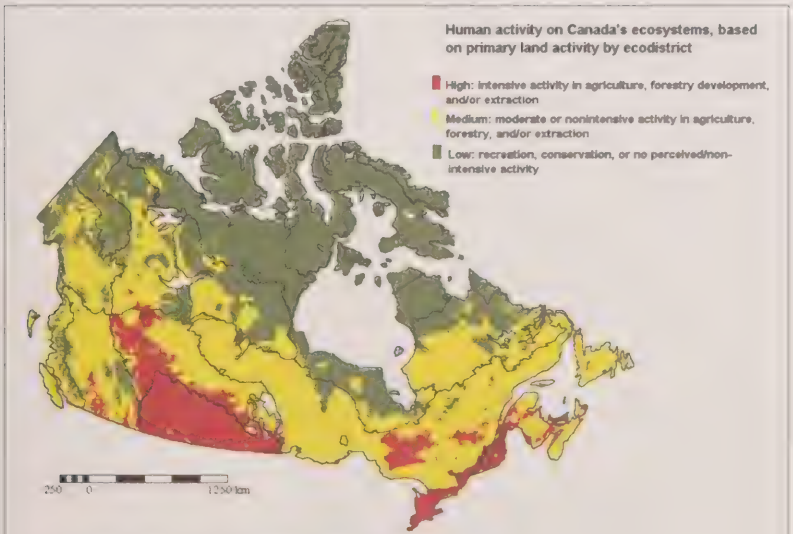
The harvesting of fish represents a large sector of economic activity but has been known to result in serious stresses on wild fish populations and, possibly, on the aquatic ecosystems they inhabit. Several important fish stocks — including freshwater species such as Blackfin, Shortjaw, and Shortnose ciscoes and Acadian and Lake Simcoe whitefish and marine fishes such as the Atlantic Salmon and several stocks of Atlantic Cod — have experienced significant declines in this century; furthermore, the Blue Walleye and Deepwater and Longjaw ciscoes are now extinct. Pacific salmon have experienced alternating high and low populations owing to a combination of human factors, such as harvesting, and environmental factors, such as ocean climate variability and change (e.g., see Chapter 11) and fluctuations in prey species (e.g., Pacific Herring) (Environment Canada 1994).

Table 14.4
Known Canadian examples of vertebrate extinctions

Species	Class	Last recorded	Probable causes
Great Auk	Bird	1844	Hunting
Labrador Duck	Bird	1878	Hunting, habitat alteration
Sea Mink	Mammal	1894	Trapping
Dawson's Caribou (subspecies of Woodland Caribou)	Mammal	1910	Hunting
Passenger Pigeon	Bird	1914	Hunting, habitat alteration
Deepwater Cisco	Fish	1955	Commercial fishing, introduced predators
Blue Walleye	Fish	1965	Habitat alteration, commercial fishing
Longjaw Cisco (Great Lakes)	Fish	1978	Commercial fishing, introduced predators
Banff Longnose Dace	Fish	1987	Introduced predators

Source: Banfield (1974); Groombridge (1992).

Figure 14.5
Relative degree of human activity on Canada's ecosystems



Source: Biodiversity Science Assessment Team (1994).

In recent years, the demand for fish has grown and the technology of fishing has advanced to a point where harvests of some species show declines in the average size and age of individuals. A change in the composition of the catch has also occurred owing to complex changes in the ecosystem. The change in catch composition is illustrated in Table 14.5.

For many species, such as cod, the link between population numbers and harvesting may be due to a combination of interacting factors, including changing environmental and habitat conditions, disease, and predation, as well as resource use.

Exotic introductions

Introduced species compete with other species occupying the same habitat. The more tolerant and aggressive the new species is in its new home, the more likely the native species are to decline. Introductions of various species have affected about 20% of birds at risk globally (Diamond 1987). The introduction of exotic birds such as the House Sparrow and European Starling to North America (see Chapter 10) increased the overall number of species in Canada. Aggressive competition for nest sites by some newcomers has reduced numbers of native birds such as the Eastern Bluebird, Red-headed Woodpecker, and Cliff Swallow (Godfrey 1986).

The introduction of plants of European or Eurasian origin has affected biodiversity in Canada (White et al. 1993; Mosquin et al. 1995). Plants were brought to this country accidentally, often with animal fodder, in sacks of seed grain, or even lodged in the clothing of the colonists. Several weed plants have invaded natural ecosystems in one or more ecozones (Table 14.6). Purple Loosestrife, an attractive European wildflower, threatens many freshwater marshes in eastern

Canada, where it has crowded out native wetland plants, dramatically changing the species composition of marsh communities and diminishing waterfowl habitat. Leafy Spurge, another introduced species, has threatened grassland habitats by outcompeting native species for moisture and light.

Of the 3 137 species of vascular plants known to grow wild in British Columbia, 662 (21%) are aliens that have been introduced by human agency (Harding 1994). In Point Pelee National Park, 37% of the vascular plants are nonnative, and some species such as Garlic Mustard and Purple Loosestrife are rapidly replacing native plants and altering plant community structure.

Some of the best-known examples of introduced species occur in the Great Lakes (see Chapter 6). One of them, the Sea Lamprey, is a parasitic fish that is believed to have entered the upper Great Lakes through the Welland Canal in 1921 (Mosquin et al. 1995). It killed large numbers of native species of fish and was largely responsible for the demise of Lake Trout in the Great Lakes. The introduction of the Rainbow Smelt is thought to have contributed to the extinction or endangerment of several species of Great Lakes ciscoes and the Lake Simcoe Whitefish (Burnett et al. 1989). Another introduction, the Zebra Mussel, has recently spread throughout the Great Lakes–St. Lawrence system — it occupies large areas of underwater habitat and displaces native species of clams and other molluscs, and its filter-feeding "efficiency" reduces the amount of plankton available to native filter feeders and larval fishes. It also significantly affects light penetration and abundance of submergents in lakes and rivers (Mosquin et al. 1995).

Genetically modified organisms, created through biotechnology, represent a new type of introduction that could potentially pose a risk to biodiversity. Potential risks include creating novel traits that cause the genetically modified organism to become more invasive of natural habitats and the risk of gene transfer to other organisms that might persist in the environment (Edge 1994). Although genetically modified organisms may equally have beneficial effects, the uncertainty is cause for concern.

Chemical pollutants

Human beings introduce a vast array of chemical substances into the environment. Some chemicals are simply the waste products of industrial processes. Others are compounds — such as insecticides and herbicides — that have been designed to produce environmental changes.

Wastes and by-products

Effluent and emissions introduce a complicated mix of chemicals into Canada's air and waters. Domestic sewage and the effluent from food processing plants can overload aquatic ecosystems with nutrients, rendering waters uninhabitable for most fish and many invertebrates. Other industrial processes are the source of heavy metals, dioxins, polychlorinated biphenyls (PCBs), and other toxic contaminants found in the flesh of fish, mammals, and aquatic birds. Some chemicals are implicated in reduced reproductive success or increased incidence of cancers and physical defects among fish and fish-eating birds (Government of Canada 1991). Toxic chemicals can also induce genetic changes that compromise the ability of species to survive and reproduce.

Industrial emissions of sulphur and nitrogen oxides give rise to acidic precipitation. The results include soil and water acidification, reductions in the availability of nutrients for plants and animals in both terrestrial and aquatic ecosystems, and the death of aquatic organisms (Government of Canada 1991). Some fish have disappeared from lakes in the southern Boreal Shield ecozone.

Yet another airborne chemical threat to biodiversity, not only in Canada but also on a global scale, is the presence in the stratosphere of chlorofluorocarbons (CFCs). These chemicals contribute to the destruction of stratospheric ozone, reducing its ability to filter out solar ultraviolet radiation. Increased ultraviolet radiation could seriously harm a wide range of photosynthesizing plants and has been speculatively linked to the global decline of amphibian populations.

Chemical applications

Fertilizers increase crop yields, whereas pesticides help protect crops. However, the effects of these chemicals are not exclusively beneficial. Inorganic fertilizers can suppress the action of soil enzymes, whereas the runoff of animal manure and synthetic fertilizers can result in eutrophication of aquatic ecosystems (Sly 1991). Routine use of pesticides diminishes soil and water quality and frequently harms beneficial wildlife.

Pesticides, consisting mostly of herbicides and insecticides, are used in Canada's forests to enhance the success of tree plantations (most often to help conifer seedlings outgrow broadleaf competition) and to control severe outbreaks of insect pests. Some broad-spectrum insecticides have serious negative effects on forest songbirds, both directly, by killing them or reducing reproductive success, and indirectly, by reducing the availability of their insect prey (Ernst et al. 1989). These insecticides are also known to kill important insect pollinators, such as bumblebees. These concerns have led to the virtual elimination of the use of broad-spectrum chemical pesticides in forestry. They have been replaced by narrow-spectrum biological pesticides and by an integrated pest management approach that balances prevention, detection, and suppression techniques.

Table 14.5

Changes in species composition in Georges Bank between 1963 and 1986

Species	Percentage of catch 1963	Percentage of catch 1986
Cod	55	11
Skate	22	33
Flounder	12	3
Dogfish	2	41

Source: Sissenwine and Cohen (1991).

Calls to Action

The human population of the world has doubled since 1950 and now stands at over 5.5 billion (WRI 1994). This figure is expected to double again in the next half century, before levelling off at 11 or 12 billion. The resulting pressures on ecosystems and species will be overwhelming. As much as a quarter of the world's species could be extinct within 40 years, severely compromising future options for food, fibre, and medicines. Ecological processes necessary to maintain life may also be in jeopardy.

Nations around the world are recognizing the severity of the ecological degradation that threatens the future of the human race. This recognition has led to a series of calls for action to save the environment.

In 1980, the World Conservation Strategy, jointly published by the IUCN, the United Nations Environment Programme (UNEP), and the World Wildlife Fund (WWF), presented the message that humanity exists only as a part of nature and stressed that human activities are threatening our "life support systems" (IUCN et al. 1980).

In 1987, *Our common future*, produced by the World Commission on Environment and Development, explored the concepts of global interdependence and the relationship between economics and the environment.

In 1991, the IUCN, UNEP, and WWF released *Caring for the Earth,* a sequel, in a sense, to the World Conservation Strategy of a decade earlier. Its declared aim was twofold: to promote and secure commitment to a new ethic of sustainable living and to integrate the goals of conservation and development.

In 1992, the World Resources Institute, IUCN, and UNEP published the Global Biodiversity Strategy, which contains guidelines for action to save, study, and use the Earth's biotic wealth sustainably

Table 14.6
Invasive plants of natural habitats in Canada

	Principal invasive plant species									
	Wetland habitats						Upland habitats			
	Eurasian Watermilfoil	European Frog-bit	Flowering Rush	Glossy Buckthorn	Purple Loosestrife	Reed Canary Grass	Common Buckthorn	Garlic Mustard	Leafy Spurge	Glossy Buckthorn
Terrestrial ecozone										
Arctic Cordillera										
Northern Arctic										
Southern Arctic										
Taiga Plains						X				
Taiga Shield										
Boreal Shield	X	X	X	X	X	X		X	X	X
Atlantic Maritime	X			X	X	X	X		X	X
Mixedwood Plains	X	X	X	X	X	X	X	X	X	X
Boreal Plains					X	X			X	
Prairies					X	X	X		X	
Taiga Cordillera										
Boreal Cordillera						X				
Pacific Maritime						X			X	
Montane Cordillera						X			X	
Hudson Plains						X				
Degree of impact										
Severe	•	•		•	•			•		•
Moderate	•	•	•	•		•				•
Limited			•							
Unknown							•		•	
Status of impact										
Spreading	•	•		•	•	•	•	•		•
Stable										
Unknown			•						•	

X = Extent of species is widespread throughout ecozone.

Source: White et al. (1993).

and equitably (WRI et al. 1992). In the same year, the United Nations Earth Summit produced a 500-page document, *Agenda 21*, which presented a road map for implementing sustainable development (UNCED 1992). Chapter 15, in particular, addressed the conservation of biodiversity and the sustainable use of biological resources. Also at the Earth Summit was the initial signing of the Framework Convention on Biological Diversity, a functioning international treaty that has since been ratified by more than 115 countries (UNEP 1992).

The Framework Convention on Biological Diversity, serving as the basis for much current action on biodiversity, acknowledges the intrinsic value of biodiversity and its vital importance to the future of evolution and the maintenance of the life-sustaining systems of the ecosphere. It points out that the conservation of biodiversity is a common concern of all humankind.

The objectives of the convention are as follows:

- the conservation of biological diversity;
- the sustainable use of ecosystems, species, and genetic material; and
- the fair and equitable sharing of benefits arising from genetic resources.

As a fundamental principle, the convention stipulates that states have a responsibility to ensure that activities within their jurisdiction or control do not do damage in areas outside their jurisdiction. It outlines a host of actions to be undertaken by each of the signatory nations. For example, each signatory nation must:

- develop national strategies for the conservation and sustainable use of biological resources;
- identify important components of biodiversity and monitor them;
- conduct in situ conservation and protection of biodiversity;
- complement in situ measures with adequate ex situ conservation, especially of genetic resources and to assist the recovery of endangered species;
- adopt measures to ensure that biological resources are used sustainably;
- cooperate with other nations in training, monitoring, and research;
- protect and share genetic resources and information on biodiversity; and
- cooperate with other nations in assuring safe access and transfer of biotechnology.

Canada, a leading proponent of the convention, ratified it in December 1992. A working group with federal, provincial, and territorial representation and multi-stakeholder advice from nongovernmental groups has since developed a Canadian Biodiversity Strategy built around five strategic goals (Federal–Provincial–Territorial Biodiversity Working Group 1995):

- to conserve biodiversity and use biological resources in a sustainable manner;
- to improve Canada's understanding of ecosystems and increase its resource management capacity;
- to promote public understanding of the need to conserve biodiversity and use biological resources in a sustainable manner;
- to maintain or develop incentives and legislation that support these goals; and
- to work with other countries to achieve the objectives of the convention.

Within these goals, there are strategic directions for each government to pursue according to its capabilities. The strategy recognizes the need to integrate conservation and sustainable use approaches. It builds on an existing base of policies, programs, and initiatives that address biodiversity, ranging from activities to protect wetlands and wildlife to strategies promoting sustainable forestry and agriculture.

Efforts to Conserve Biodiversity

The Canadian Biodiversity Strategy outlines dozens of strategic directions to support the five goals. A summary of areas where action is under way follows.

International treaties

Global conservation issues transcend political boundaries and ultimately become matters for discussion between governments. The World Conservation Monitoring Centre lists over 80 multilateral treaties that relate in one way or another to the conservation and management of biodiversity. Canada is a party to 20 of these treaties (Table 14.7), including 9 of 10 global conventions. It is also a signatory to various other treaties that indirectly relate to the conservation of biodiversity — for example, the Framework Convention on Climate Change.

Illegal trade in natural products encompasses a range of items, from bear gall bladders and rhinoceros horns to rare orchids and live parrot chicks. Since the negotiation in 1973 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), law enforcement agencies have been much better equipped to combat the illegal trade in wildlife. Species in danger of becoming extinct and threatened by international trade are listed in Appendix I of the convention, which forbids international movement of such species or their parts for any purpose other than scientific or educational purposes.

Trade in species listed in Appendix II is strictly regulated, and import and export permits are required before specimens or by-products can be shipped across borders. Not only does CITES establish a means of monitoring trade, but it also provides a context in international law for dealing with poaching and smuggling. Table 14.8 records Canadian species listed in CITES.

In situ conservation

In situ conservation consists of three main methods. One is the protection of spaces large enough to support ecosystem processes and species diversity. The second is the re-creation of those spaces through species recovery programs. A third is through the sustainable use of biological resources outside of protected areas.

Table 14.7

Canada's participation in selected multilateral treaties that serve to help protect biodiversity

Treaty	Explanation	S	N	Objectives
Global	International Plant Protection Convention (Rome), 1951		N	To maintain and increase international cooperation in controlling pests and disease of plants and plant products, to prevent introduction and spread of these pests and disease across national boundaries.
	Convention on Fishing and Conservation of the Living Resources of the High Seas (Geneva), 1958	S		To improve conservation of the living resources of the high seas and prevent overexploitation.
	Convention on the High Seas (Geneva), 1958	S		To codify the rules of international law relating to the high seas.
	Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar), 1971		N	To stem the progressive encroachment on and loss of wetlands, to recognize ecological functions of wetlands and their economic, cultural, scientific, and recreational value.
	Convention Concerning the Protection of the World Cultural and Natural Heritage (Paris), 1972		N	To establish an effective system of collective protection of cultural and natural heritage of outstanding universal value, organized on a permanent basis and in accordance with modern scientific methods.
	Convention on International Trade in Endangered Species of Wild Fauna and Flora (Washington), 1973		N	To protect certain endangered species from overexploitation via import/export controls.
	United Nations Convention on the Law of the Sea (Montego Bay), 1983	S		To set up a comprehensive new legal regime for the sea and oceans as far as environmental provisions are concerned, to establish material rules concerning environmental standards as well as enforcement provisions dealing with pollution of the marine environment.
	International Tropical Timber Agreement (Geneva), 1983		N	To provide an effective framework for cooperation and consultation between countries producing and consuming tropical timber, to promote the expansion and diversification of international trade in tropical timber, to improve structural conditions in the tropical timber market, to promote research and development, to promote sustainable utilization and conservation of tropical forests and their genetic resources, and to maintain the ecological balance in regions concerned.
	United Nations Framework Convention on Biological Diversity (Rio de Janeiro), 1992	S		Conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and technologies, and by appropriate funding.
Regional	The Antarctic Treaty (Washington), 1959		N	To ensure that Antarctica is used for peaceful purposes, for international cooperation in scientific research, and does not become the scene or object of international discord.
	Protocol to the Antarctic Treaty on Environmental Protection (Madrid), 1991	S		To reaffirm the status of the Antarctic as a special conservation area and to enhance the framework for the protection of the Antarctic environment with its dependent and associated ecosystems.
	Convention on the Conservation of Antarctic Marine Living Resources (Canberra), 1980		N	To safeguard the environment and protect the integrity of the ecosystem of the seas surrounding Antarctica, and to conserve Antarctic marine living resources.

continued on next page

Table 14.7 (continued)

Canada's participation in selected multilateral treaties that serve to help protect biodiversity

Treaty	Explanation	S	N	Objectives
Fisheries	International Convention for the High Seas Fisheries of the North Pacific Ocean (Tokyo), 1952, 1962, 1978		N	To ensure maximum sustained productivity of the fishery resources of the North Pacific Ocean, to coordinate research and conservation measures to this end.
	International Convention for the Conservation of Atlantic Tunas (Rio de Janeiro), 1966		N	To maintain populations of tuna and tuna-like fish in the Atlantic Ocean at levels permitting the maximum sustainable catch for food and other oceans.
	Protocol to the International Convention for the Conservation of Atlantic Tunas (Paris), 1984	S		See treaty above.
	Convention on Conduct of Fishing Operations in the North Atlantic (London), 1967	S		To ensure good order and conduct on the fishing grounds in the North Atlantic area.
	Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries (Ottawa), 1978		N	To promote the conservation and optimum utilization of the fishery resources of the northwest Atlantic area within a framework appropriate to the regime of extended coastal state jurisdiction over fisheries, and accordingly to encourage international cooperation and consultation.
	Convention for the Conservation of Salmon in the North Atlantic Ocean (Reykjavik), 1982		N	To promote the conservation, restoration, enhancement, and rational management of salmon stock in the North Atlantic Ocean through international cooperation, as well as the acquisition, analysis, and dissemination of appropriate scientific information.
Plants	North American Plant Protection Agreement (Yosemite), 1976		N	To strengthen intergovernmental cooperation in plant quarantine and plant protection in North America in order to prevent the introduction and spread of plant pests and noxious weeds and to foster the preservation of plant resources of North America.
Other	Agreement on Conservation of Polar Bears (Oslo), 1973		N	To achieve protection of the Polar Bear as a significant resource of the Arctic region through further conservation and management measures.

N: not yet in force
S: signature only

Note: Global treaties have no requirements as to membership and are open to any country in the world.
Regional treaties limit membership, normally to a certain geographic region.
Species-related treaties (i.e., fisheries, plants, other) limit membership to countries that have some relationship with the species that are the subject of the treaty.

Source: UNEP (1989); Environment Canada (1992b); Groombridge (1992).

Protected areas

Protected areas are portions of ecosystems in which human activities are carefully managed and certain activities that harm ecological processes are prohibited. Generally, protected areas enable ecosystems to have a nucleus or core that is relatively free from human activity. Increasingly, the conservation of biodiversity is a prime management objective. Such protection is key to maintaining the diversity and integrity of ecosystems and as such makes protected areas an important element in various management strategies. They are not, by themselves, the answer to in situ conservation of biodiversity.

However, protected areas do increase the odds of survival for the full range of their living components. Also, if fully representative portions of ecosystems can be protected, it follows that representative samples of species and genetic material stand a good chance of being protected as well.

Protected areas are known by a number of names, including ecological areas, wildlife management areas, parks, and conservation areas. Each type operates with different management objectives. Some offer near-complete protection of biotic and abiotic components from direct human disturbance. Others extend protection to selected ecosystem components, such as wildlife or soils. The number, area, and distribution of major types of protected areas are outlined in Chapter 10.

The IUCN has developed guidelines for categorizing the full range of protected areas found around the world (Box 14.4). They attempt to capture the objectives of protected areas and the degree of human intervention required or allowed within them.

The IUCN categories of protected areas can be used to compare and assess the various types of protected areas found in Canada. By extension, these categories also facilitate comparisons between Canada and the rest of the world. For example, areas protected in Canada can be compared with those of Figure 14.6, which summarizes the protection status for North America as a whole as well as the other continents.

Private stewardship provides a valuable supplement to the public networks of protected areas. The North American Waterfowl Management Plan (a trilateral agreement among the United States, Canada, and Mexico) offers incentives to encourage private landowners to conserve wetlands for wildlife, rather than filling or draining them for agricultural and development purposes. Nongovernmental agencies such as Ducks Unlimited are major partners in implementing the plan. Thousands of hectares of productive wetland ecosystems that could never be bought outright by public agencies are thereby secured for the long-term protection of biodiversity. Table 14.9 lists nongovernmental organizations that have secured areas for their conservation activities.

Private individuals are also being encouraged to conserve biodiversity. Through recent amendments to Canada's federal *Income Tax Act*, donations of ecologically significant lands to government or charities receive favourable tax treatment.

One indicator of the commitment to protect ecosystems is the growth in protected areas (Fig. 14.7). Since the creation of

Table 14.8

Canadian species included in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 1992

Mammals	Birds	Reptiles and amphibians	Fish	Plants
Appendix I[a]				
Bison, Wood Cougar, Eastern Ferret, Black-footed Whale, Blue Whale, Bowhead Whale, Fin Whale, Humpback Whale, Right Whale, Sperm	Crane, Whooping Curlew, Eskimo Eagle, Bald Falcon, Peregrine Goose, Aleutian Canada Gyrfalcon	Turtle, Leatherback	Sturgeon, Shortnose	
Appendix II[b]				
Bear, Black Bear, Grizzly Bear, Polar Bobcat Cougar Lynx, Canada Otter, River Otter, Sea Seal, Northern Elephant Whales Wolf	Crane, Sandhill Diurnal birds of prey[c] Hummingbirds[d] Owls[d]	Boa, Rubber Turtle, Bog Turtle, Wood	Sturgeon, Atlantic	Cacti[d] Ginseng Orchids Plant, Pitcher
Appendix III[e]				
Walrus				

[a] Appendix I species are rare or endangered, and trade will not be permitted for primarily commercial purposes. Before trade for other purposes can proceed, the importer must obtain a Convention export permit issued by the government of the exporting nation and an import permit issued by the Canadian Wildlife Service, Environment Canada

[b] Appendix II species are not rare or endangered but could become so if trade is not regulated. The species being traded must be covered by appropriate Convention export permits issued by the government of the exporting nation before entry to Canada will be permitted.

[c] Includes all falcons, hawks, and eagles not listed in Appendix II.

[d] Includes all family members (except any listed in Appendix I)

[e] Appendix III species are not endangered but are managed within the listing nation Permit requirements for Appendix III species are the same as those for Appendix II species

Source: Environment Canada (1992a)

Banff National Park in 1885, the amount of protected area in Canada has grown to almost 800 000 km^2, or about 8% of the country. About half that area could be considered strictly protected from major resource extraction activities (corresponding roughly to IUCN categories I–III).

Figure 14.8 shows the relative sizes of different types of protected areas in Canada.

Ecological representation

In November 1992, the federal, provincial, and territorial ministers responsible for environment, parks, and wildlife issued a joint commitment to make every effort to complete Canada's networks of protected areas (representing Canada's land-based natural regions) by the year 2000. These areas include hundreds of nationally and provincially administered ecological reserves, parks, wildlife areas, and other protected areas.

Of Canada's 217 terrestrial ecoregions, 146 (67% of the country) are protected to some degree by some form of legislation. Thirty-three of these regions (15% of the country) enjoy a high level of protection (i.e., greater than 12% of the ecoregion protected by IUCN categories I–III). However, 71 ecoregions, which collectively occupy 33% of the country, currently have no protected areas. Table 14.10 presents complete figures for the range of protected areas, whereas Figure 14.9 shows maps

Box 14.4

IUCN categories of protected area: defining characteristics and typical management practices

IUCN category	Defining characteristics	Management goals or practices	Canadian example
I. Nature reserve or wilderness area			
a. Nature reserve	Possesses some outstanding or representative ecosystems, geological or physiographic features, or species	Primarily for scientific research or ecological monitoring	Oak Mountain Ecological Reserve (New Brunswick)
b. Wilderness area	Large areas, unmodified or slightly modified, retaining their natural character and influence, without permanent or significant habitation	Preservation of natural conditions	Bay du Nord Wilderness Area (Newfoundland)
II. National park (or equivalent)	Designated to sustain the integrity of one or more ecosystems, exclude exploitation or intensive occupation, and provide a foundation for scientific, educational, recreational, and visitor opportunities, all which must be ecologically and culturally compatible	Ecosystem protection and recreation	Banff National Park (Alberta)
III. Natural monument	Contains one or more specific natural or cultural features of outstanding or unique value because of inherent rarity, representative of aesthetic qualities, or of cultural significance	Protection of specific outstanding natural features, provision of opportunities for research and education, and prevention of exploitation or occupation	Parrsboro Fossil Cliffs (Nova Scotia)
IV. Habitat/species management areas	Areas important for ensuring the maintenance of habitats or for meeting the requirements of certain species	Securement and maintenance of habitat conditions necessary to protect species and ecosystem features where these require human manipulation for optimum management	Watshishou Migratory Bird Sanctuary (Quebec)
V. Protected landscape or seascape	Areas where interactions of people and nature have produced a distinct character with significant cultural or ecological value and often with high biodiversity	Conservation, education, recreation, and provision of natural products aimed at safeguarding the integrity of harmonious interactions of nature and culture	Algonquin Provincial Park (Ontario)
VI. Managed resource protected areas	Predominantly natural areas that are large enough to absorb sustainable resource uses without harming long-term maintenance of biodiversity	Long-term protection and maintenance of biodiversity and other natural values and the promotion of sound management practices for sustainable production purposes	Battle Creek Community Pasture (Saskatchewan)

Source: After IUCN (1994).

of protected space in groupings of IUCN categories.

Major gaps in ecosystem representation occur in the southern prairies, most ecoregions of the Southern Arctic ecozone and the three Taiga ecozones, and the most densely populated regions of Ontario and Quebec. Underrepresented ecosystems in southern Canada are difficult to protect because they are often highly modified through various activities associated with human settlement and economic activities and because they are most often privately owned. Among the best-represented areas are many ecoregions of the Montane, Boreal, and Arctic Cordillera ecozones.

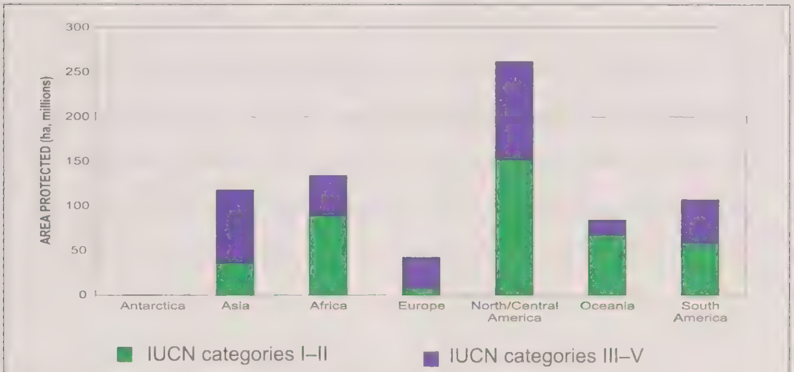
In recent years, there has been an increasing recognition that protecting marine ecosystems, their components, and their ecological processes is as important as protecting terrestrial ecosystems. Although Canada has lagged behind some other developed countries in protecting marine areas, there are encouraging signs. The most recent is the effort to establish Canadian marine conservation areas (Department of Canadian Heritage 1995). Most activity has been on the west coast, where two large expanses of marine areas are protected. Another marine conservation area has been established at the confluence of the Saguenay and St. Lawrence rivers, where the marine waters and uneven topography have provided a high level of biological productivity that attracts large populations of whales and other marine mammals and supports large concentrations of endemic plant species. Marine conservation areas are designed to include sustainable use zones in which commercial fishing can continue. The proposed Canada Oceans Act also has provisions for the establishment of marine protected areas.

The provinces are increasingly looking to protect marine environments. British Columbia has established a number of ecological reserves in marine areas. These reserves protect both unique and representative nearshore resources from degradation and exploitation and will aid the restoration of various marine ecosystems.

Some of Canada's protected areas are designated under the terms of international treaties or agreements that recognize the areas for their contribution to global conservation goals (Table 14.11; Fig. 14.10). The Ramsar Convention provides a framework for the conservation of "wetlands of international importance." World heritage sites, designated under the Convention Concerning the Protection of World Cultural and Natural Heritage, may include areas of particular scientific or aesthetic value, geologically unique or important sites, and the habitats of endangered species. Both Ramsar sites and world heritage sites in Canada may be designated without being formally protected. These programs therefore help to identify candidate sites for formal protection.

Biosphere reserves, established under the United Nations Educational, Scientific and Cultural Organisation's (UNESCO) Man and the Biosphere (MAB) Programme, respond to a wider range of objectives, including scientific research, training, monitoring, and demonstration, as well as conservation. A typical reserve consists of

Figure 14.6
Summary of protected areas, by continent



Note: 1. Values for Antarctica are 215 649 ha for IUCN categories I–II and 36 700 ha for IUCN categories III–V.

2. The IUCN categories described in this figure differ from those used in the text, as a new IIUCN category III was added in 1994 (see Box 14.4).

Source: Groombridge (1994).

Table 14.9
Conservation lands owned or managed by selected nongovernmental organizations, 1993

Organization	No. of sites	Total area (ha)
Ducks Unlimited Canada	7 892	964 784
Nature Conservancy of Canada	191	36 339
Alberta Fish and Game Association	292	25 481
British Columbia Nature Trust	92	11 589
Manitoba Wildlife Federation	77	10 419
Ontario Heritage Foundation	[illegible]	2 400
Federation of Ontario Naturalists	13	547
Ruiter Valley Land Trust	1	175
New Brunswick Nature Trust	5	94
Total	[illegible]	1 051 828

Source: State of the Environment Directorate, Environment Canada

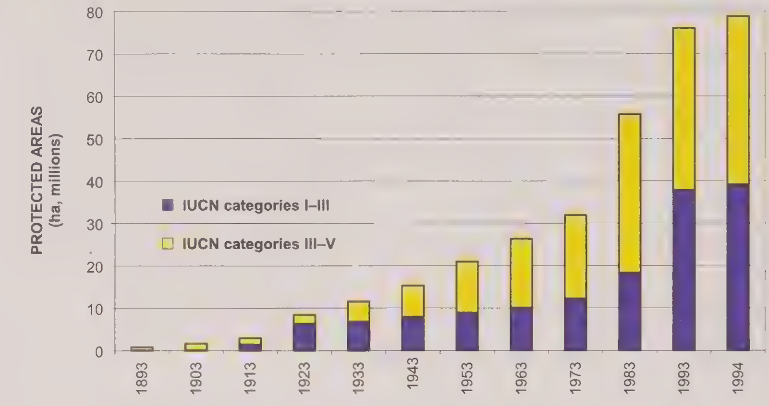
a strictly protected core area surrounded by a buffer in which intrusive activities are controlled. Around these elements is a large "zone of cooperation," where a full range of human activities occurs and where ecological restoration and sustainable resource use can be demonstrated. Increasingly, biosphere reserves are seen as part of a family of model areas for conservation and sustainable development.

Restoration and rehabilitation
The inextricable link between species and ecosystems is perhaps best understood by those concerned with species recovery and rehabilitation programs. Species may be restored only if the ecosystems that support them are rehabilitated. Canada's commitment to reviewing the status of certain classes of native flora and fauna under COSEWIC has already been noted. A complementary program, Recovery of Nationally Endangered Wildlife (RENEW), is developing recovery plans for some 35 species that have been designated by COSEWIC as extirpated, endangered, or threatened.

Several species protection or reintroduction programs have been implemented with encouraging results. Peregrine Falcons have been restored to territories from which they had been extirpated. Sea Otters have been reintroduced to the kelp forests off the west coast of Vancouver Island. The Wood Bison has been downlisted from endangered to threatened, and the Ferruginous Hawk has been downlisted from threatened to vulnerable. The American White Pelican and the Prairie Long-tailed Weasel, two formerly threatened prairie species, have been delisted entirely. The wild population of Whooping Cranes, while still endangered, has increased more than 10-fold since 1944, under an intensive program of protection and restoration.

At present, the RENEW program focuses on terrestrial vertebrate species. However, as noted elsewhere, plants, invertebrates, fungi, and algae greatly outnumber vertebrates in the roll call of species diversity and in many instances perform more vital ecological functions. The knowledge base on the identification and ecological role of these groups is far from complete. How to respond effectively to threats to these taxa is a matter for consideration by governmental and nongovernmental agencies. One practical step, taken in 1994, was to broaden the *Canada Wildlife Act* to apply to all wild organisms.

Figure 14.7
Growth in the establishment of protected areas in Canada



Note: The IUCN categories described in this figure differ from those used in the text, as a new IUCN category III was added in 1994 (see Box 14.4).

Source: State of the Environment Directorate, Environment Canada.

Ex situ conservation

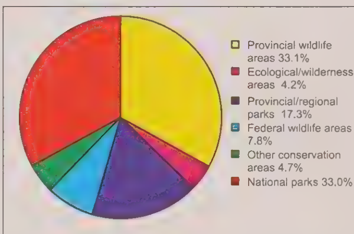
A complementary approach to the in situ conservation of biodiversity is ex situ conservation — that is, the conservation of species or genetic materials under artificial conditions, away from the ecosystems to which they belong. As the supply of natural habitat diminishes, the maintenance of captive (or, in the case of plants, cultivated) populations has been accepted as one of the few ways to ensure the survival of an increasing number of species. The long-term goal is to restore them to the wild in at least some of their original ranges.

Ex situ facilities also offer opportunities for public education about species on display, thereby building broader public support for their conservation in situ. Table 14.12 demonstrates the range of ex situ facilities across Canada.

Plants
Around the world, there are more than 1 500 botanical gardens, of which about 800 are committed to conserving rare, endemic, or otherwise threatened plant species (Groombridge 1992).

In Canada, 60 botanical gardens house close to 40 000 plant species from Canada and around the world (Mosquin et al. 1995). Specimens of at least 11 endangered, rare, or vulnerable native plant species are being maintained in these botanical gardens, as well as some 300

Figure 14.8
Percentages of different types of protected areas in Canada



Source: State of the Environment Directorate, Environment Canada

Table 14.10

Status of ecoregion protection based on amount of protected area, 1995

% of ecoregion protected by IUCN categories I–III	No. of ecoregions	% of Canada	% of ecoregion protected by IUCN categories I–VI	No. of ecoregions	% of Canada
0	87	40	0	71	33
>0–3	49	22	>0–3	51	23
>3–6	23	11	>3–6	28	13
>6–9	16	7	>6–9	19	9
>9–12	9	5	>9–12	10	5
>12	33	15	>12	38	17
Total	217	100	Total	217	100

Source: State of the Environment Directorate, Environment Canada.

exotic species. At present, however, none of these is being actively propagated specifically for reintroduction.

Seed banks are another important type of ex situ facility for conserving plant species and genetic diversity. Worldwide, 528 institutions are known to have facilities for seed handling and storage. Many of these are coordinated through the International Board for Plant Genetic Resources.

Agriculture and Agri-Food Canada maintains seed stocks of some 800 species of plants, most of them exotic varieties that are required in plant breeding. Canadian Forest Service holdings include the seeds of 240 species of forest trees, many native to other countries (Mosquin et al. 1995). These are stored and used as integral aspects of sustainable use programs. One nongovernmental initiative, the Heritage Seed Program, maintains a large variety of vegetable species in its network.

Animals

Global efforts to preserve both wild and native animal biodiversity ex situ are concentrated in 878 zoos and aquariums, with a total of over 1 million vertebrate specimens (Groombridge 1992). Increasingly, these institutions have shifted their focus from entertainment to providing living conditions that simulate the natural habitat of various species accurately enough to promote breeding. For species that are extinct or have precariously low numbers in the wild, survival depends on captive breeding programs aimed at building up their numbers to the point where they can be returned to their native ecosystems.

Specimens of at least 12 endangered, threatened, or vulnerable native animal species are held in Canadian zoos. Species represented include the Whooping Crane, Ferruginous Hawk, Eastern Massasauga Rattlesnake, Wood Bison, Great Grey Owl, Red-shouldered Hawk, Spotted Turtle, Grizzly Bear, and Polar Bear. Canadian captive breeding programs have supplied Swift Foxes and Peregrine Falcons for reintroduction programs, and the Metropolitan Toronto Zoo is currently raising Black-footed Ferrets for future release into their natural habitat (Mosquin et al. 1995). Some Canadian zoos are part of an international network of sites that breed non-Canadian species for reintroduction to their native ecosystems in other countries.

In addition to publicly funded institutions, there are many private game farms and wildlife preserves that can fulfil a role in research and education on the conservation of wild animals. However, it must be recognized that not all species can be propagated in captivity.

Sustainable use of biological resources

Despite in situ and ex situ conservation efforts, the global threat to biodiversity posed by growing human populations and the resultant increased resource consumption and pressure on biodiversity continue to intensify. There is a broad consensus among environmental specialists that present and projected levels of consumption cannot be sustained (World Commission on Environment and Development 1987). The best hope for satisfying basic human economic needs without compromising biodiversity is the rigorous adoption of sustainable use policies and practices in all resource sectors. In Canada, this will have particular significance for three primary industries: agriculture, forestry, and fisheries.

Sustainable agriculture and biodiversity[2]

The expansion and intensification of agriculture raise several issues that relate to biodiversity: the protection of soil and water quality, sustainable management of land features that may provide habitat for wildlife, and conservation of agricultural genetic resources.

The protection of healthy levels of soil biodiversity is of vital importance to sustainability in agriculture. The methods farmers use to manage their soil resources will be critical to their ability to produce adequate supplies of food in years to come. The increased use of conservation tillage methods reduces erosion and, if timed correctly, may also enable birds and other native fauna to reproduce successfully.

2. Chapter 11 provides a more extensive discussion of agriculture.

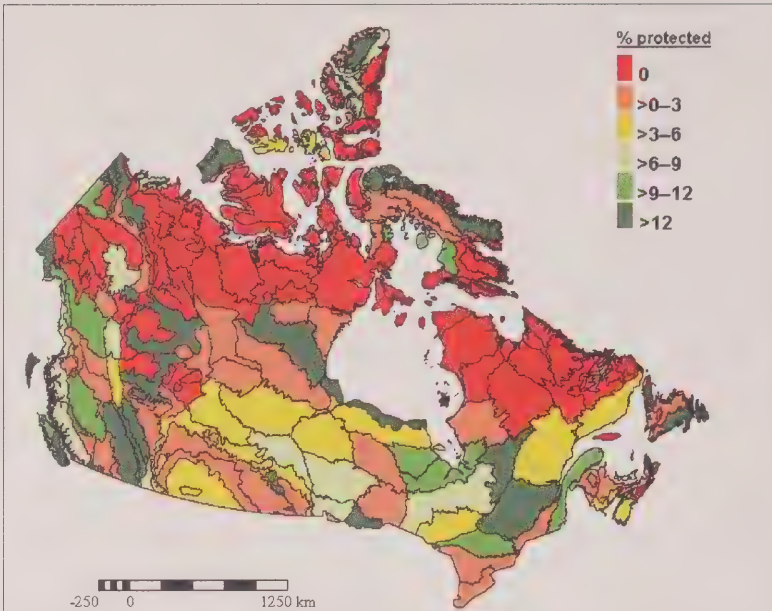
Increased use of organic fertilizers and avoiding waste in the application of fertilizers have been shown to help restore the quality of soil and water, benefit soil fauna, and reduce input costs to farmers without diminishing crop yields. Biological control methods, integrated pest management strategies, and the use of biotechnology to produce disease- and pest-resistant crop varieties are all reducing the negative impacts of pesticides on ecosystem health. Through efforts aimed at reducing the use of toxic materials, 29 different compounds affecting more than 2 000 agriculture-related products have been controlled through legislation or banned entirely.

Biodiversity on agricultural lands can be sustained and enhanced by setting aside some land for wildlife habitats, which may actually benefit farm productivity as well. Preserving or planting woodlots and hedgerows reduces erosion damage and provides shelter for wildlife species that prey on crop-eating pests. Protection of areas along streambanks reduces flooding, nutrient loading, and chemical discharges. Conservation of wetlands in agricultural settings offers a degree of drought protection by sustaining a higher water table and provides habitat for waterfowl and other aquatic wildlife. High-yield strains of crops and intensive production methods, which produce more food in less space, offer the hope of an eventual restoration of some native ecosystems that have been lost to agriculture. Certain cropping practices have been shown to help improve biodiversity in the soil while improving yields (Mineau and McLaughlin 1994).

This century has witnessed a rapid shrinking of agricultural crop varieties. For example, apple varieties common 100 years ago are now rare or extinct, as are various domesticated animal breeds (Table 14.13). Most Holstein cows can be traced to a handful of bulls. To ensure that domesticated crops and animals provide food for future generations, the genetic material of the original and developed varieties must be maintained. This maximizes the potential for healthy, disease-resistant, genetically diverse species. Agriculture and Agri-Food Canada programs to maintain germplasm of crop varieties are linked

Figure 14.9a

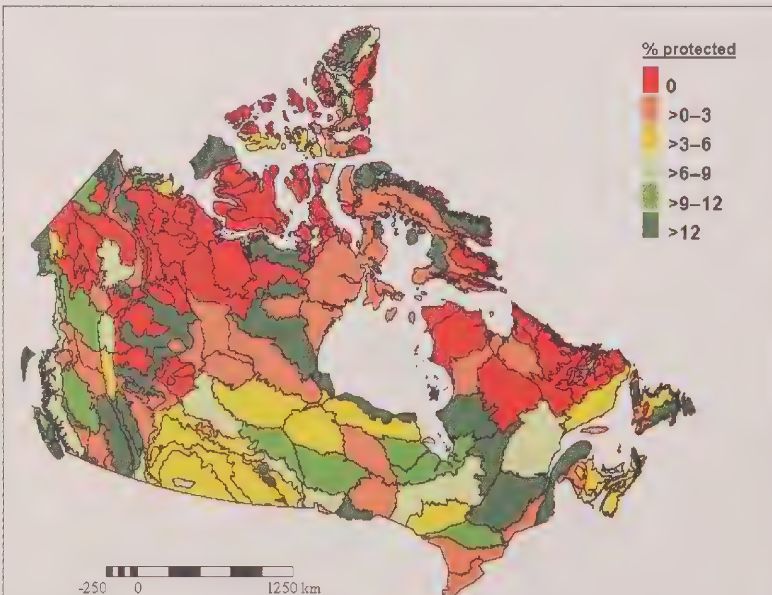
Highly protected space (IUCN categories I–III), by ecoregion



Source: State of the Environment Directorate, Environment Canada.

Figure 14.9b

All protected space (IUCN categories I–VI), by ecoregion



Source: State of the Environment Directorate, Environment Canada.

Table 14.11
Internationally designated protected areas in Canada

Name	Ecozone	Prov.	Area (ha)	Year established
Canadian world heritage sites				
Anthony Island (South Moresby)	Pacific Maritime	BC	149 500	1981
Canadian Rocky Mountain Parks	Montane Cordillera	BC	2 306 884	1993
Dinosaur Provincial Park	Prairies	AB	9 050	1979
Gros Morne National Park	Boreal Shield	NF	194 250	1987
Head-Smashed-In Buffalo Jump	Prairies	AB	200	1981
Historic District of Quebec	Mixedwood Plains	QC	135	1985
Kluane National Park Reserve	Boreal Cordillera	YT	2 201 330	1979
L'Anse aux Meadows	Boreal Shield	NF	1	1978
Nahanni National Park Reserve	Taiga Plains	NT	476 520	1978
Wood Buffalo National Park	Taiga Plains	AB	4 480 200	1983
Canadian Ramsar sites				
Alaksen National Wildlife Area	Pacific Maritime	BC	299	1982
Baie de L'Isle-Verte National Wildlife Area	Boreal Shield	QC	2 028	1987
Beaverhill Lake	Prairies	AB	18 050	1987
Cap Tourmente National Wildlife Area	Boreal Shield	QC	2 398	1981
Chignecto National Wildlife Area	Atlantic Maritime	NS	1 020	1985
Creston Valley	Montane Cordillera	BC	6 970	1994
Delta Marsh	Prairies	MB	23 000	1982
Dewey Soper Migratory Bird Sanctuary	Northern Arctic	NT	815 900	1982
Grand Codroy Estuary	Boreal Shield	NF	925	1987
Hay–Zama Lakes	Taiga Plains	AB	50 000	1982
Lac St-François National Wildlife Area	Mixedwood Plains	QC	2 214	1987
Last Mountain Lake	Prairies	SK	15 602	1982
Long Point National Wildlife Area	Mixedwood Plains	ON	13 730	1982
Malpeque Bay River Wetlands Area	Atlantic Maritime	PE	24 440	1988
Mary's Point	Atlantic Maritime	NB	1 200	1982
McConnell River Migratory Bird Sanctuary	Southern Arctic	NT	32 800	1982
Mer Bleue	Mixedwood Plains	ON	1 300	1995
Musquodoboit Harbour Outer Estuary	Atlantic Maritime	NS	1 925	1987
Oak Hammock Marsh Wildlife Management Area	Prairies	MB	3 600	1987
Old Crow Flats	Taiga Cordillera	YT	617 000	1982
Peace–Athabasca Delta	Boreal Plains	AB	321 300	1982
Point Pelee National Park	Mixedwood Plains	ON	1 564	1987
Polar Bear Pass Reserve National Wildlife Area	Northern Arctic	NT	262 400	1982
Polar Bear Provincial Park	Hudson Plains	ON	2 408 700	1987
Queen Maud Gulf Migratory Bird Sanctuary	Southern Arctic	NT	6 278 200	1982
Quill Lakes	Prairies	SK	63 500	1987
Rasmussen Lowlands	Northern Arctic	NT	300 000	1982
Shepody Bay	Atlantic Maritime	NB	12 200	1987
Southern Bight–Minas Basin	Atlantic Maritime	NS	26 800	1987
Southern James Bay (Hannah Bay Migratory Bird Sanctuary)	Hudson Plains	ON	23 830	1987
Southern James Bay (Moose River Migratory Bird Sanctuary)	Hudson Plains	ON	1 460	1987
St. Clair River National Wildlife Area	Mixedwood Plains	ON	244	1985
Tabusintac Estuary and Lagoon	Atlantic Maritime	NB	4 382	1993
Whooping Crane Summer Range	Boreal Plains	AB	1 689 500	1982
Canadian biosphere reserves				
Charlevoix Biosphere Reserve	Boreal Shield	QC	448 000	1988
Long Point National Wildlife Area	Mixedwood Plains	ON	26 250	1986
Mont-Saint-Hilaire Biosphere Reserve	Boreal Shield	QC	5 500	1978
Niagara Escarpment	Mixedwood Plains	ON	207 000	1990
Riding Mountain National Park	Boreal Plains	MB	975 000	1986
Waterton Lakes National Park	Montane Cordillera	AB	62 000	1979

Source: State of the Environment Directorate, Environment Canada

to several global institutions that maintain the germplasm of original plants, as well as other varieties and domesticated species. Nongovernmental agencies such as Rare Breeds Canada and the Heritage Seed Program have a network of over 500 farms that raise rare and endangered domestic breeds and maintain cryogenic collections for cattle and sheep.

Sustainable forestry and biodiversity[3]

About 45% of Canada's land area is forest and taiga (see Chapter 10). The forests are a critically important repository of biodiversity, providing essential habitat for 131 species of trees and for thousands of other species of forest flora and fauna (Middleton 1994).

Sustainable forestry includes biodiversity conservation. An awareness that forest ecosystems, not just trees, should be the focus of management policies and practices is clearly reflected in the commitment expressed in Canada's National Forest Strategy to "strengthen the foundations for conserving the natural diversity of our forests, and putting in place the fundamental reporting systems to say where we stand." The strategy recommends incorporating scientific research into forest management and planning systems to improve basic understanding of forest ecosystems and species. It urges partnerships among governmental agencies, industry, labour organizations, Aboriginal groups, academia, conservation groups, and the general public in implementing and monitoring these new systems.

Forest ecosystems are highly varied, as are methods of management and timber harvesting. The interests of forest biodiversity may be adequately served by balancing appropriate harvest methods with the establishment of untouched forest reserves. In some cases, it may be more sound, both ecologically and economically, to harvest less aggressively and more selectively (Botkin 1990; Kimmins 1992). As the appreciation of biodiversity grows, greater interest is being shown in protecting old-growth forest, preserving organic nutrients on site, conserving supplies of nonfragmented wildlife habitat, the use of biological pest controls, and the use of fire to prepare for natural regeneration. In many instances, harvesting is being planned so that biologically diverse forest ecosystems can coexist with a viable commercial forest industry.

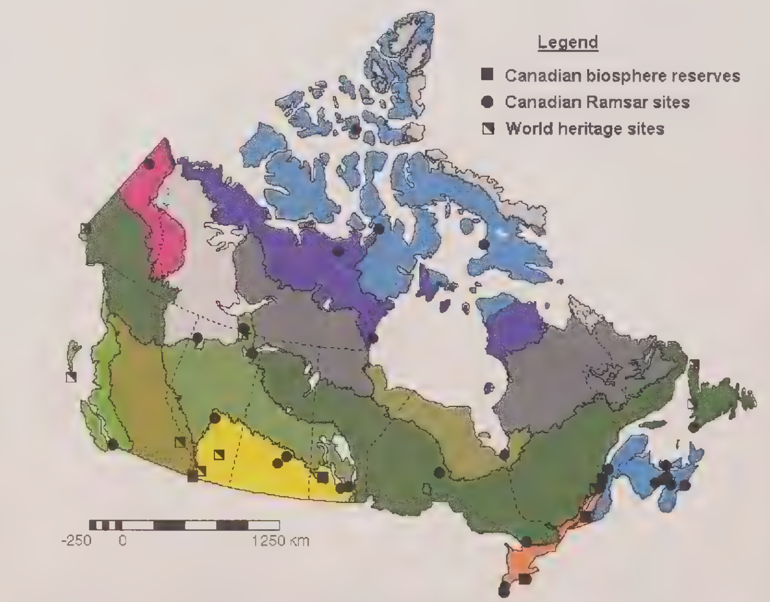
The National Forest Strategy, a blueprint for change in Canadian forests, was developed cooperatively by federal, provincial, and territorial governments and interest groups. The strategy outlines several commitments that will support efforts to manage forested ecosystems ecologically.

In response to the National Forest Strategy, Canada has established a network of model forests. These provide an innovative way to attempt the integration of social, cultural, environmental, and economic values into sustainable forest management. Since the program was announced in 1991, 10 model forest sites have been established across the country, ranging in size from roughly 1 000 to 15 000 km^2. Each site represents a different mix of environmental, social, and economic conditions. Activities in model forests are designed to be managed through promoting of partnerships involving industry and environmental and conservation groups, Aboriginal communities, private landowners, and all levels of government. They are intended to function as productive economic units, but also to serve as living laboratories where research can be conducted into wildlife habitat use, indicators of the state of the ecosystem, and other matters of crucial importance to the conservation of biodiversity.

The Canadian Council of Forest Ministers is pursuing the development of criteria and indicators of sustainable forest management. Environmental, social, and economic criteria have been developed that define sustainable forest management. The six criteria developed are as follows (Canadian Criteria and Indicators Working Group 1995):

Figure 14.10

Distribution of internationally designated protected areas within Canada



Source: State of the Environment Directorate, Environment Canada.

3. Chapter 11 provides a more extensive discussion of forestry.

- conservation of biological diversity;
- maintenance and enhancement of forest ecosystem condition and productivity;
- conservation of soil and water resources;
- forest ecosystem contributions to global ecological cycles;
- multiple benefits to society; and
- accepting society's responsibility for sustainable development.

Initiatives are under way to develop a series of measurable indicators for these criteria. This process involves determining how Canada's information and data collection efforts need to be changed in order to facilitate reporting on the indicators.

On the global stage, Canada, along with many other countries, has been working towards obtaining a common understanding of sustainable forest management. The 1990 G-7 meeting in Houston, Texas, called for an international forest convention to help curb deforestation, protect biodiversity, and address threats to forests. To that end, the 1992 Earth Summit in Rio de Janeiro, besides producing the Framework Convention on Biological Diversity, also produced a statement of forest principles representing a global consensus as part of *Agenda 21*.

Since then, international efforts have focused on defining a comprehensive set of criteria and indicators of sustainable forest management for use by policy makers. One initiative, the Montreal Process — which includes 10 non-European countries, including Canada, that collectively represent 90% of the world's temperate and boreal forests — completed and endorsed a comprehensive set of criteria very similar to those associated with the Canadian initiative outlined above. Sixty-seven indicators have been associated with these criteria, which will guide policy makers in the participating countries.

Other international organizations and conferences are also developing criteria and indicators of sustainable management, including:

- the International Tropical Timber Organization, which published *Criteria for the measurement of sustainable tropical forest management* in 1992;
- the Second Ministerial Conference on the Protection of Forests in Europe, held in Helsinki, Finland, in June 1993, which resulted in a set of criteria and indicators that were agreed to in June 1994; and
- a Regional Workshop on the Definition of Criteria and Indicators for Sustainability of Amazonian Forests, which was held in Tarapoto, Peru, in February 1995.

In an effort to move forward on the *Agenda 21* commitments, the third session of the United Nations Commission on Sustainable Development (UNCSD) decided to create an Open-ended Intergovernmental Panel on Forests to review progress on implementing United Nations Conference on Environment and Development (UNCED) forest commitments. The panel will focus on the following five general themes:

- implementation of UNCED decisions related to forests at the national and international level, including an examination of sectoral and cross-sectoral linkages;
- international cooperation in financial assistance and technology transfer;
- scientific research, forest assessment, and development of criteria and indicators for sustainable forest management;

Table 14.12
Ex situ conservation facilities in Canada

Type of facility	Approximate no. of facilities	Species: Group	Species: Approximate no.
Zoos	50	Mammals	200
		Birds	200
		Reptiles	150
		Amphibians	50
		Fish	150
		Invertebrates	70
Aquariums	15	Mammals	30
		Birds	20
		Reptiles	50
		Amphibians	25
		Fish	1 500
		Invertebrates	300
Aviaries	15	Mammals	50
		Birds	300
		Reptiles	10
		Fish	5
Botanical gardens (includes arboretums)	60	Plants	40 000
Germplasm/seed/gene banks	30	Seeds/germplasm	2 000
Microbial culture collections	150	All types[a]	4 000
Herbaria	220	Plants	<100 000
Museums[b]	100	Mammals/birds	500
		Reptiles/amphibians	850
		Fish	4 000
		Invertebrates	40 000

[a] Includes bacteria 47%; fungi 30%; yeasts 10%; bacterial viruses 6%; others 7%.
[b] Holdings consist largely of study collections of nonliving specimens.

Source: Mosquin et al. (1995).

Table 14.13
Selected domestic breeds that have become extinct since 1892

Continent	Cattle	Goat	Horse	Pig	Sheep
Europe	157	18	59	79	96
Asia	27	27	23	29	52
North America	1	1	4	17	10
South America	19	0	0	0	0
Africa	22	0	3	0	1
Oceania	2	0	1	1	2

Source: Groombridge (1992).

- trade and environment relating to forest products and services; and
- international institutions and instruments, including appropriate legal mechanisms.

The panel will present its final report to the UNCSD at its 1997 session.

Sustainable fisheries and biodiversity[4]
The presence of fish species and their population levels are important indicators of the state of biodiversity in aquatic ecosystems. Fish occupy a wide range of ecological niches within their respective habitats. Unfortunately, the history of fishing in Canada, on both marine and inland waters, has been marked by a series of declines in the stocks of targeted species.

Many factors other than fishing may influence the availability of fish stocks. Some species have strong preferences for particular habitat conditions. Change in the complex interaction of ecological characteristics may cause an entire population to crash or be eliminated from the area. Given such ecosystem unpredictability, aquaculture may be an important sustainable alternative to the wild fishery, providing it does not displace or degrade ecosystems or cause introductions of exotic species. Aquaculture can help reduce pressure on wild fish stocks, enabling marine ecosystems to recover. The use of aquaculture has been growing dramatically in recent years. The production volume of the east and west coast salmon industries has grown 100-fold since the early 1980s. Other large-scale aquaculture species include the Blue Mussel, oysters, and trout (Department of Fisheries and Oceans 1993). Aquaculture is not without its own problems, however — among which are the escape of exotic species into the environment and genetic alteration of genomes (D.E. McAllister, Canadian Museum of Nature, personal communication).

Canada has argued strongly before the United Nations and other international bodies for the global management of fisheries on a sustainable basis. Fish can be harvested sustainably only when there is reasonable certainty that their average rate of recruitment matches the rate of capture and when a buffer is allowed as a precautionary measure against environmental changes. The decision to declare and enforce moratoriums on commercial fishing of Atlantic Salmon and Atlantic Cod is an acknowledgement that the restoration of depleted stocks may take years. In order to obtain meaningful conservation measures in international waters, Canada is playing an active role in the negotiation of a new United Nations Convention on Straddling Fish Stocks and Highly Migratory Fish Stocks. The convention should provide an effective enforcement mechanism for fishing regulations on the high seas. Canada is also participating in the negotiation of a Code of Conduct for Responsible Fishing.

Many techniques of fishing and fishery management are available to help rebuild or maintain fish stocks at sustainable levels. Protection of access to spawning rivers and the maintenance of excellent water quality are important factors in ensuring that fish species such as salmon will be able to reproduce successfully. Even if fishing were stopped entirely, fish stocks would still fluctuate with changing environmental conditions.

Despite ongoing efforts by governments and industry, effective management of a sustainable fishery in Canada is still not assured. Little is known about the dynamics of aquatic ecosystems. Continued study will be required into the life histories, interactive roles, and ecological functions of lesser-known aquatic species. Research and development of fishing gear designed to avoid by-catch mortality and minimize damage to habitat, as well as evaluation of the impact of nonfishery-related stresses on aquatic biodiversity, need to be continued. Baseline studies of aquatic ecosystems and monitoring of populations and habitats are a foundation of such research. The creation of marine protected areas, for the express purpose of conserving aquatic biodiversity, may also be necessary. The proposed Canada Oceans Act contains provisions for establishing marine protected areas for the purposes of conservation and protection of biodiversity.

Improving the understanding of biodiversity

A key to realizing the conservation of biodiversity and the sustainable use of biological resources is to adopt ecological management principles. Ecological management includes the management of human activities so that the biotic and abiotic components of ecosystems and the processes that shape them continue. It follows that this must be based on adequate understanding of ecosystems and species and the impacts of human activities upon them. The current state of this knowledge is inadequate, and a strong commitment to research is required.

As a starting point for research, reliable baselines and indicators are essential prerequisites for understanding and conserving biodiversity. There is an urgent need to

4. Chapter 11 provides a more extensive discussion of fisheries.

develop standardized protocols for conducting surveys and inventories. This will help make it possible to document and compare species and ecosystems at risk. Equally important is the continuation of work to establish indicators of biodiversity change that will permit the detection and tracking of trends and will serve to inform and guide public discussion towards wise environmental choices.

A number of innovative strategic tools have been developed to accelerate the pace of biodiversity research. One, which is already in use in Canada to assist in completion of a representative protected area network, is known as gap analysis. The objective of the technique is to identify gaps in the representation of biodiversity in areas that have been designated for the preservation of native species and ecosystems (Scott et al. 1993). Using comprehensive ground surveys and inventories, along with satellite imagery and geographic information system technology, gap analysis can establish a firm basis for conservation evaluation. A related tool is hot spot analysis, which aids in locating areas of species or endemic richness that should have priority for protection, sustainable use, or new biotechnologies.

Areas designated for biodiversity management are invaluable resources for the present and future acquisition of taxonomic, biogeographic, and ecological knowledge. One ambitious proposal for the gathering and analysis of such information is the All Taxa Biodiversity Inventory (ATBI) concept (Janzen and Hallwachs 1994). An ATBI project would require the concentrated efforts of researchers to identify, locate, and enumerate all the species within the boundaries of the chosen area. Next, the complex ecological interactions and relationships must be described. Finally, the results of the research effort must be disseminated as widely as possible. The high financial and time costs of ATBI work indicate that it should be complemented with other efforts with more immediate benefit to the conservation of species and ecosystems.

Biodiversity inventories on this scale add both impetus and much-needed order to another area of exploratory research that holds the promise of important ecological, scientific, and economic benefits. Biodiversity prospecting is a term that describes the search for wild species that may yield new medicines, lend vigour to food crops, and provide solid economic arguments for conservation as well as consumption as the dominant way of dealing with nature and natural areas (Reid et al. 1993). In addition, research collections and databases in government departments, museums, and herbaria, although they do not consist of living plant material, are of vital importance to taxonomic research.

Efforts to monitor the status of biodiversity are being made at a number of levels. Regional monitoring programs, such as those coordinated through the federal Ecosystem Monitoring and Assessment Network (EMAN) program, will monitor a wide variety of ecosystem and species parameters to assess the interactions and sustainability of regional ecosystems. One means to collect and share information on biodiversity is through conservation data centres, currently located in five provinces and linked to more than 80 centres in the western hemisphere. Another, more decentralized means under way is the establishment of on-line electronic networks of centres of biodiversity data and information. National and global networks could be used to share new knowledge about biodiversity and its uses around the world. Effectively linked and accessible information could support decision making for both development and conservation planning and in environmental impact assessments.

Currently at the global level, the World Conservation Monitoring Centre collects, analyzes, and distributes national data on biodiversity and protected areas. It provides global assessments on the status of biodiversity that can aid policy makers at national levels and at international agencies such as the United Nations.

Conclusion: The Task Ahead

The business of understanding and conserving biodiversity and sustainably managing biological resources and ecosystems promises to preoccupy society for the foreseeable future. The magnitude of the crisis posed to the ecosphere by the human species demands it. The directions documented in the international Framework Convention on Biological Diversity and the Canadian Biodiversity Strategy must be incorporated into policies and programs of governments and nongovernmental organizations and the actions of individual citizens.

The nature of the crisis is demonstrated by the fact that, at the present rate of extinction, it is conceivable that the majority of the species now on Earth may disappear before their existence and value are even known. Forestalling this potential catastrophe will require a strong political will to direct public policy in a number of directions. Maintaining the natural processes required to support the diversity of ecosystems and species can be achieved only through an ecosystem approach to management. An unprecedented commitment to research and an energetic program of public education are also needed. With a growing human population, societies must develop strategies for reducing levels of consumption.

A strategy for sustainable living is embodied in the principles set out in *Caring for the Earth* (IUCN et al. 1991). The strategy argues that society must conserve the Earth's vitality and diversity by:

- conserving the life support systems that nature provides;
- conserving the diversity of life on Earth; and
- ensuring that all uses of renewable resources are sustainable.

This returns to the essence of sustainability: to care for the Earth in such a way that the optimum benefit can be derived from its resources without depleting or exhausting them. The task is at once inspiring and humbling. Attaining and promoting a better understanding of the concepts and complexities of biodiversity can be an important step towards achieving the wisdom needed to preserve it.

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Chapter 15 Atmospheric Change

Highlights

Stratospheric ozone depletion and an enhanced greenhouse effect both have the potential to jeopardize the Earth's life support system.

■

Efforts to control greenhouse gas emissions are hampered by a lack of conclusive evidence that human activities are leading to global warming. However, scientists agree that the rate and patterns of climate change over the past century, taken together, point towards a discernible human influence on global climate.

■

If measures are not taken to reduce human-related emissions of greenhouse gases, the global mean temperature could increase during the next century by between 0.1°C and 0.5°C per decade, leaving the average global temperature higher than at any time in the past 100 000 years.

■

If the climate evolves as anticipated, sea levels would rise, inundating some coastal areas; areas suitable for agriculture could shift, leading in some cases to increased crop yields, given appropriate soils; tropical pests and diseases could penetrate currently nontropical regions; certain forests could become more productive; and many plant and animal species could become extinct if warming proceeded too quickly for them to adapt or migrate.

■

Stratospheric ozone provides a natural shield against many of the more harmful wavelengths of ultraviolet radiation. When sufficiently intense, ultraviolet radiation can break stable chemical bonds and damage deoxyribonucleic acid (DNA), the genetic coding material that living things carry in their cells.

■

Stratospheric ozone depletion has been linked primarily to chlorofluorocarbons (CFCs), the family of stable, nontoxic, nonflammable chemicals first developed in the 1890s.

■

International agreements, beginning with the Montreal Protocol of 1987, have led to a dramatic decline in the production and consumption of ozone-depleting substances. However, depletion of the ozone layer is not a fully resolved problem, as purely benign substitutes for some CFCs are still unavailable at present.

■

The move to control ozone-destroying substances represents a major success story in international cooperation. Scientific inquiry led to a high level of certainty surrounding the issue and the implementation of sound environmental policies worldwide.

■

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Introduction

The steam engine is one of those landmark developments that identify and symbolize an era. Perfected by Thomas Newcomen and James Watt in the 1700s, it liberated the energy of fossil fuels for powering machinery and helped launch the industrial revolution. It also helped open a new chapter in the history of the atmosphere.

The Earth's atmosphere — the thin film of gases that is crucial to the sustainability of life on this planet — has evolved over some 4.5 billion years, modified by geological, biological, and other natural forces. But with the coming of the industrial revolution, as symbolized by the steam engine, human productivity and technological creativity also became forces of atmospheric change.

At first glance, the atmosphere appears to have changed little since Newcomen's day. Excluding water vapour and atmospheric particulates, 99.9% of the atmosphere still consists of nitrogen, oxygen, and argon. It is the remaining 0.1%, the atmospheric trace gases, that is now being substantially altered by human activities. These activities are of two kinds: the production of gases that enhance the Earth's natural "greenhouse effect" and are strongly suspected of leading to global climate change; and emissions of substances, such as chlorofluorocarbons (CFCs), that destroy stratospheric ozone, the Earth's natural shield from harmful ultraviolet radiation.

This chapter explores these two issues in atmospheric change. It outlines the scientific evidence that links human activities and atmospheric change and briefly surveys the physical, biological, and societal implications of such change. Also summarized are actions that have been taken to mitigate these changes.

Climate Change

Greenhouse gases and climate

The most important of the greenhouse gases are carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O), and water vapour. These gases perform ecologically critical functions, such as regulating air temperature. Even small changes in their atmospheric concentrations can have serious consequences for the stability of natural ecosystems and the well-being of human societies.

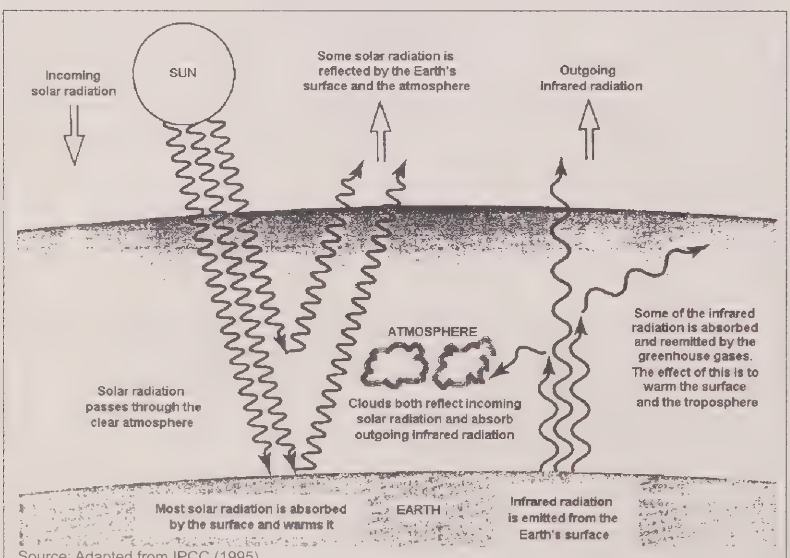
"Climate" results from exchanges of energy and moisture within the earth–ocean–atmosphere system. Thus, anything that alters the distribution of energy within the system or the amount of energy entering or leaving the Earth's atmosphere must inevitably change the planet's climate. The importance of the greenhouse gases stems from this simple fact.

The earth–ocean–atmosphere system is warmed by absorption of shortwave radiation from the sun, which is converted to longwave infrared radiation. The system cools by releasing this infrared radiation back towards space. Greenhouse gases play a critical role in this energy exchange, because they retard the loss of heat from Earth to space, thereby raising the temperature of the Earth's surface and surrounding air (Fig. 15.1). Because of this natural greenhouse effect, the Earth's mean surface temperature of 15°C is some 33°C warmer than it would otherwise be — enough to make the difference between a living and a lifeless planet.

The magnitude of greenhouse warming depends on the quantities of the various greenhouse gases in the atmosphere and their relative efficiencies as absorbers and emitters of radiation. Water vapour is the most abundant of these gases and contributes about 21°C of warming to the natural greenhouse effect. Carbon dioxide, although less abundant than water vapour, is a much more efficient absorber of radiation and accounts for another 7°C of warming. Ozone, methane, and nitrous oxide are responsible for the remaining 5°C (Barry and Chorley 1992).

These gases enter the atmosphere via a number of natural processes. Water vapour does so through evaporation and transpiration. Plant and animal respiration, combustion, and the decay of organic matter in soils and the oceans are the main contributors of carbon dioxide. Chemical reactions in the soil account for most of

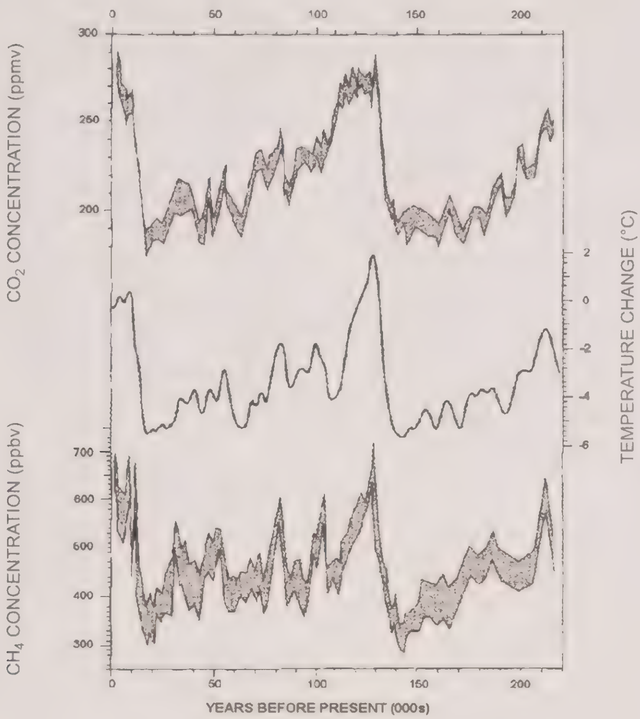
Figure 15.1
Energy flow in the global climate system



Source: Adapted from IPCC (1995).

Figure 15.2

Variation of proxy air temperature over Antarctica and of global atmospheric carbon dioxide and methane concentrations during the last 220 000 years, as inferred from the Vostok ice core



ppmv = parts per million by volume
ppbv = parts per billion by volume

Shaded area represents the range of uncertainty in the estimate

Source: Adapted from IPCC (1995), after Jouzel et al. (1993).

the naturally produced nitrous oxide, whereas much of the naturally produced methane results from the decay of organic matter in wetlands.[1] Ozone is produced within the atmosphere through various chemical reactions.

Eventually, these gases are removed from the atmosphere by a variety of natural processes, reaching an assortment of destinations or "sinks." For example, water vapour returns to Earth as precipitation, carbon dioxide is absorbed into the oceans, and forests and agricultural crops remove additional carbon dioxide as they grow. When sources and sinks are in balance, atmospheric concentrations of greenhouse gases remain stable. If the balance is upset, concentrations change until a new balance is established. Other factors being constant, the resulting change in greenhouse gas concentration will also alter temperatures at the Earth's surface.

Analyses of ancient air bubbles trapped inside ice cores taken from the polar ice caps enable scientists to study the relationship between greenhouse gases and air temperature during the last 220 000 years. During that time, the global climate has undergone several radical changes, emerging from one ice age, plunging into another, and entering into warm periods such as the present. As Figure 15.2 shows, these studies reveal a close correlation between greenhouse gas concentrations and changes in local proxy (i.e., as inferred from the chemical composition of the ice) air temperatures in the Antarctic during this time. This relationship does not prove that changes in greenhouse gas concentrations alone caused the onset and decline of the ice ages — indeed, periodic variations in the position of the Earth with respect to the sun are considered the most significant cause — but it does suggest that greenhouse gases had an important role in the process, possibly as amplifiers of the original changes.

Human activities and the greenhouse effect

Since the beginning of the industrial revolution nearly 250 years ago, concentrations of greenhouse gases have increased substantially (Table 15.1). Concentrations of carbon dioxide, for example, have increased by more than 25%, from 280 parts per million by volume (ppmv) to over 355 ppmv. There is overwhelming evidence linking at least part of this increase to human activities. In fact, about 60% of this increase has occurred since 1958, mirroring the rapid growth of a postwar global economy powered by fossil fuels (Fig. 15.3). Only about half of the carbon dioxide from these anthropogenic sources has been retained in the atmosphere. The rest has been absorbed by the oceans and forests.

Further evidence that human activities have increased atmospheric concentrations of carbon dioxide comes from Antarctic ice core analyses, which show that present concentrations of carbon dioxide are higher than any known natural values in recent geological history. Over the past 220 000 years, concentra-

1. Agricultural sources of methane, being human-related, are omitted in this context.

tions appear never to have exceeded 300 ppmv (Schimel et al. 1995). Finally, changes in the relative mix of different carbon isotopes in the atmosphere point to an increase in carbon originating from the burning of fossil fuels and forests (Leavitt and Long 1988; Watson et al. 1990; IPCC 1995).

Concentrations of other greenhouse gases have also shown major increases. Since 1750, concentrations of methane have more than doubled, whereas those of nitrous oxide have grown by nearly 13%. In addition, significant quantities of synthetic greenhouse gases, mainly CFCs and halons, have been added to the atmosphere for the first time, especially since the 1970s.

Naturally occurring stratospheric ozone is the major source of heat in the stratosphere, owing to its ability to absorb ultraviolet radiation. Depletion of stratospheric ozone by CFCs and halons should create a surface cooling effect, as less heat is reradiated downwards from the stratosphere. However, because many CFCs and halons are also powerful greenhouse gases, their increasing concentrations in the lower atmosphere are believed to more than compensate for any cooling from stratospheric ozone loss. At ground-level, increasing background ozone levels in industrialized parts of the world have added to the greenhouse effect.

The amount of water in the atmosphere is not affected significantly by its direct anthropogenic emissions or removals. However, an increase in air temperature at and near the Earth's surface would both accelerate the evaporation of surface moisture and increase the atmosphere's capacity to hold water vapour. This would increase the water vapour concentration in the atmosphere and reinforce the greenhouse effect, creating a positive feedback. It is also postulated that increased temperatures in Arctic regions would melt permafrost, releasing methane and further enhancing the greenhouse effect.

Of all the greenhouse gas emissions related to human activity, those of carbon dioxide are by far the greatest. Between 1980 and 1989, human activities released an estimated 7.1 billion tonnes of carbon into the atmosphere annually as carbon dioxide (for global and Canadian carbon dioxide emission trends, see Chapter 11). Most of this — 5.5 billion tonnes on average each year — came from the burning of fossil fuels, with a minor contribution from cement production (Table 15.2). The burning and clearing of tropical forests accounted for much of the remaining 1.6 billion tonnes (Schimel et al. 1995). Compared with the 150 billion tonnes of carbon released to and removed from the atmosphere every year by natural sources and sinks (IPCC 1995), the total contribution from human sources seems relatively small. However, it has been enough to disrupt the natural balance between carbon sources and carbon sinks.

Estimates of annual methane emissions from human-related sources range

Table 15.1

Some characteristics of key greenhouse gases affected by human activities

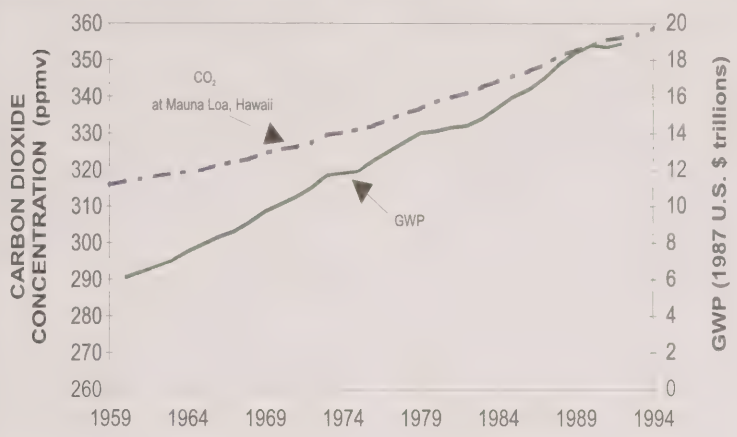
Gas	Preindustrial concentration	Concentration in 1992	Recent rate of concentration change per year (during the 1980s)	Atmospheric lifetime (years)	Global warming potential[a] (100-year time horizon)	Remarks
CO_2	280 ppmv	355 ppmv	1.5 ppmv (0.4%)	50–200[b]	1	Increase is almost entirely due to human activities
CH_4	700 ppbv	1 714 ppbv	13 ppbv (0.8%)	9–15[c]	15–27	Natural and anthropogenic
N_2O	275 ppbv	311 ppbv	0.75 ppbv (0.25%)	120	310	Natural and anthropogenic
CFC-12	0 pptv	503 pptv	18–20 pptv (4%)	102	8 500	Entirely human origin
HCFC-22 (a CFC substitute)	0 pptv	105 pptv	7–8 pptv (7%)	12.1	1 700	Anthropogenic; low concentrations now but rising
CF_4 (a perfluorocarbon)	0 pptv	70 pptv	1.1–1.3 pptv (2%)	50 000	6 500	Anthropogenic; very long lifetime; effectively a permanent atmospheric resident

ppmv = parts per million by volume
ppbv = parts per billion by volume
pptv = parts per trillion by volume

[a] Referenced to the absolute global warming potential for CO_2. Typical uncertainty is ±35% relative to the CO_2 reference.
[b] No single lifetime for CO_2 can be defined because of different rates of uptake by different sink processes.
[c] This has been defined as an adjustment time that takes into account the indirect effect of CH_4 on its own lifetime.

Source: IPCC (1995, 1996).

Figure 15.3
Atmospheric concentration of carbon dioxide since 1959, and gross world product since 1960



GWP = gross world product

Sources: *Carbon dioxide:* Keeling and Whorf (1994); C.D. Keeling (personal communication); *GWP:* Brown et al. (1995).

Table 15.2
Estimated average annual sources, sinks, and storage of carbon from human-related emissions of carbon dioxide, 1980–1989

A. Sources	
	Estimate (range)[a] (Gt/year)
Emissions from fossil fuel combustion and cement production	5.5 (5.0–6.0)
Net emissions from changes in tropical land use	1.6 (0.6–2.6)
Total	7.1 (6.0–8.2)
B. Sinks	
	Estimate (range)[a] (Gt/year)
Storage in the atmosphere	3.2 (3.0–3.4)
Oceanic uptake	2.0 (1.2–2.8)
Uptake by northern hemisphere forest regrowth	0.5 (0.0–1.0)
Additional terrestrial sinks (carbon dioxide fertilization, nitrogen fertilization, climatic effects)[b]	1.4 (0.0–2.9)
Total	7.1

[a] Upper and lower limits correspond to an estimated 90% confidence interval.
[b] Additional sinks from carbon dioxide and nitrogen fertilization arise when increases in atmospheric concentrations of carbon dioxide and nitrogen oxides from anthropogenic sources provide added nutrients needed by plants within affected ecosystems. Climate feedbacks occur when changes in temperature, precipitation, or other climate variables improve plant growth conditions and hence enhance accumulation.

Source: IPCC (1995).

between 300 and 450 million tonnes — more than twice the amount of natural emissions (Table 15.3). Agricultural sources such as rice paddies and fermentation in the digestive tracts of cattle and sheep (enteric fermentation) are the largest anthropogenic sources of this gas, followed closely by fossil fuel production. The amounts of both natural and anthropogenic emissions of nitrous oxide are unclear, although the latter may make up to 40% of estimated emissions (Table 15.4).

Estimates of CFC and halon emissions are much more precise, as these chemicals are totally synthetic and their production is well documented. These emissions are declining because of production phaseouts mandated by the Montreal Protocol on Substances that Deplete the Ozone Layer of 1987 and subsequent amendments. However, these chemicals will continue to enter the atmosphere for some time after their production has ceased, escaping from existing materials (e.g., certain foam products) or existing equipment (e.g., old refrigerators and air conditioners). In addition, some of their substitutes (e.g., hydrochlorofluorocarbons, or HCFCs) are significant greenhouse gases themselves.

Certain fluorine compounds — particularly tetrafluoromethane (carbon tetrafluoride), hexafluoroethane, and sulphur hexafluoride — have been identified as potentially significant greenhouse gases as well. Known as perfluorocarbons (PFCs), these are primarily by-products of aluminum and magnesium smelting. Although concentrations of these gases are in the low parts per trillion (ppt) range (Fabian et al. 1987; Ravishankara et al. 1993), the gases are highly efficient radiation absorbers, and they have molecular lifetimes of thousands of years.

The additional warming caused by increased concentrations of greenhouse gases and their ultimate impact on climate depend partly on their radiative characteristics (i.e., the types and amounts of energy they absorb and emit) and their residence time in the atmosphere (see Table 15.1). Even though it is

the least efficient absorber of infrared radiation, carbon dioxide has the greatest impact of all the human-related greenhouse gases, because human-related emissions of this gas are considerably higher than those of the others and because additional quantities of it may take anywhere from 50 to 200 years to return to sinks in the oceans and forests.

Although, tonne for tonne, methane absorbs 15–27 times as much infrared radiation as does carbon dioxide over a 100-year time frame (IPCC 1996), its direct impact on global warming is significantly smaller, for two reasons. First, methane emissions are approximately 20 times less than emissions of carbon as carbon dioxide. Second, methane remains in the atmosphere for a much shorter time — an estimated 9–15 years.

Emissions of nitrous oxide are, in turn, roughly 1 000 times lower than emissions of carbon as carbon dioxide; however, nitrous oxide absorbs 310 times as much infrared radiation as an equal mass of carbon dioxide over a 100-year time frame and has an atmospheric lifetime of 120 years (IPCC 1996).

The most powerful of all the greenhouse gases, however, are the CFCs and PFCs. A tonne of CFC-12, for example, absorbs 8 500 times as much infrared radiation as a tonne of carbon dioxide over a 100-year time frame and has an estimated atmospheric lifetime of 102 years (IPCC 1996).

Taking absorptive efficiency, atmospheric lifetime, and other factors into consideration, it has been estimated that carbon dioxide accounts for about 64% of the additional greenhouse warming since preindustrial times, methane 19%, nitrous oxide 6%, and CFCs and halons 11% (Shine et al. 1995). However, except for methane, these calculations are based only on the direct warming effect of these gases and do not consider the indirect effects that some of these gases may have on the climate system. For example, the surface cooling effect that results from the depletion of stratospheric ozone partially offsets the warming contribution of CFCs and halons (IPCC 1995).

Predicting climate change

To analyze the climatic effect of increasing concentrations of greenhouse and other gases, scientists are employing computer models of the climate system. The models are based on the physical laws that govern the behaviour of the earth–ocean–atmosphere system and use mathematical equations that describe these laws to predict future climates. They allow researchers to conduct experiments on the climate

Table 15.3
Estimated annual sources and sinks of methane

A. Identified sources	
	Estimate (range)[a] (Mt/year)
Natural sources	
Wetlands	115 (55–150)
Termites	20 (10–50)
Oceans	10 (5–50)
Other	15 (10–40)
Total identified natural sources	**160 (110–210)**
Anthropogenic sources	
Individual fossil fuel-related sources	
Natural gas	40 (25–50)
Coal mines	30 (15–45)
Petroleum industry	15 (5–30)
Coal combustion	? (1–30)
Total fossil fuel-related sources	**100 (70–120)**
Biospheric carbon	
Enteric fermentation	85 (65–100)
Rice paddies	60 (20–100)
Biomass burning	40 (20–80)
Landfills	40 (20–70)
Animal waste	25 (20–30)
Domestic sewage	25 (15–80)
Total biospheric sources	**275 (200–350)**
Total identified anthropogenic sources	**375 (300–450)**
Total identified sources	**535 (410–660)**
B. Sinks	
	Estimate (range)[a] (Mt/year)
Atmospheric removal (lifetime = 9.4 years)	
Tropospheric hydroxyl radical	445 (360–530)
Stratosphere	40 (32–48)
Soils	30 (15–45)
Total sinks	**515 (430–600)**
C. Atmospheric increase	
	Estimate (range)[a] (Mt/year)
Observed value	37 (35–40)[b]

[a] Most data are rounded to the nearest Mt.
[b] The observed atmospheric increase in methane (35–40 Mt/year) implies a somewhat greater total source than currently identified.

Source: Adapted from IPCC (1995).

system that would be impossible (or inadvisable) to carry out in the real world.

The scope and complexity of these models vary considerably, but the most elaborate are the general circulation models (GCMs) that represent the workings of the major elements of the climate system — the sun, atmosphere, oceans, land surfaces, soils, vegetation, and ice — and simulate their interaction in three dimensions over time. It must be recognized, however, that GCMs have their limitations. Although they represent some physical processes with mathematical precision, they portray others (e.g., cloud or ice formation) with less accuracy. Much more intricate computer models are available for individual phenomena such as cloud formation, but they are problematic in other respects. For example, such models are often designed to function at a far more detailed geographic scale than possible within a GCM. Hence, whereas there is reasonable agreement in GCM predictions at the global scale for such climate variables as air temperature, atmospheric circulation, and sea level, there remain large uncertainties with respect to such global variables as precipitation patterns. More importantly, models are as yet unable to predict realistically the effects of global changes in climate on the subcontinental and regional characteristics of future climate and weather.

Table 15.4
Estimated annual sources and sinks of nitrogen from natural and anthropogenic emissions of nitrous oxide

A. Identified sources	
	Estimate (range) (Mt/year)
Natural sources	
Oceans	3 (1–5)
Tropical soils	
Wet forests	3 (2.2–3.7)
Dry savannas	1 (0.5–2.0)
Temperate soils	
Forests	1 (0.1–2.0)
Grasslands	1 (0.5–2.0)
Total identified natural sources	**9 (6–12)**
Anthropogenic sources	
Cultivated soils	3.5 (1.8–5.3)
Biomass burning	0.5 (0.2–1.0)
Industrial sources	1.3 (0.7–1.8)
Cattle and feed lots	0.4 (0.2–0.5)
Total identified anthropogenic sources	**5.7 (3.7–7.7)**
Total identified sources	**14.7 (10–17)**
B. Sinks	
	Estimate (range) (Mt/year)
Stratosphere	12.3 (9–16)
Soils	?
Total sinks	**12.3 (9–16)**
C. Atmospheric increase	
	Estimate (range) (Mt/year)
Observed value	3.9[a] (3.1–4.7)

[a] The observed atmospheric increase implies that sources exceed sinks by 3.9 Mt/year, instead of the 2.4 Mt/year difference between total sources and total sinks shown here.

Source: Adapted from IPCC (1995).

Most of our present understanding of the potential climatic impact of greenhouse warming comes from experiments with "doubled carbon dioxide" climates — the simulated climate that results when the model's atmosphere has a stable carbon dioxide concentration of about 560 ppmv, or twice the preindustrial concentration.[2] Doubled carbon dioxide experiments have been performed in several countries using a number of different models. The most recent experiments (e.g., Manabe and Stouffer 1994; Mitchell et al. 1995) have used advanced atmospheric GCMs coupled to ocean GCMs to represent important ocean processes. Results from these experiments differ, sometimes widely, depending on the sophistication of the models and the approaches used in modelling different features of the climate system. Nevertheless, the models agree that, with a doubling of carbon dioxide over preindustrial levels:

- The average global surface air temperature would eventually increase by 1.5–4.5°C, with a best estimate of 2.5°C. However, the warming would not be distributed uniformly over the globe. The greatest warming would occur in higher latitudes in winter and the least in the tropics; continental interiors would warm more than the oceans.
- The stratosphere would become cooler.
- Average global precipitation and evaporation would increase by 3–15%. Most models predict that soil moisture in northern mid-latitudes would decrease during summer in the continental interiors.
- Sea ice cover and seasonal snow cover in the northern hemisphere would decrease.

2. A doubled carbon dioxide climate may also be one resulting from a combination of greenhouse gases with a greenhouse warming effect equivalent to a doubling of carbon dioxide.

- Globally, sea level would rise at an increasing rate.

On the basis of these results, the Intergovernmental Panel on Climate Change (IPCC) — the international body of experts that is synthesizing the results of climate change studies — has predicted that if measures are not taken to stabilize or reduce emissions of greenhouse gases, global mean surface air temperatures will increase during the next century by between 0.1°C and 0.5°C per decade (IPCC 1996). This would be the fastest rate of temperature change by far in human history and would likely raise the average surface air temperature by about 1°C over present values by 2025 and by about 3°C before the end of the next century.

Impact of an enhanced greenhouse effect

For the people of a high-latitude country such as Canada, the prospect of a warmer climate, especially a warmer winter, can be appealing. However, it is important to realize that changes in climatic elements other than air temperature would likely occur — changes that might not necessarily be for the better, and changes that are not necessarily foreseeable. Such uncertainties are a matter of concern in their own right.

Changes of the magnitude just described would leave average global temperatures higher than at any time in the past 100 000 years. These changes could also occur very quickly, allowing little time to adapt to new conditions or develop countermeasures that would slow or reverse the course of events.

The impact of an enhanced greenhouse effect on human societies and natural ecosystems would depend primarily on how regional climates respond. Regional responses, in turn, would depend not only on how local factors such as evaporation and soil moisture change but even more so on how the circulation patterns of both the atmosphere and the oceans evolve. Changing circulation patterns would cause some regions to warm dramatically, others to warm only moderately, and others (e.g., possibly the North Atlantic region off the coast of Labrador) to cool. At the same time, storm tracks could shift, causing some areas to receive more precipitation and others less.

The most significant consequences of climate change could arise through changes in the magnitude and/or frequency of extreme events such as thunderstorms, hurricanes, heat waves, and episodes of drought. Small changes in the mean climate — or, more importantly, in climate variability — can produce comparatively large changes in the frequency of extreme events. Although there is little agreement between models on changes in extreme events, some tentative conclusions can be made. A general warming, for example, would tend to lead to an increase in the number of days with extremely high temperatures in summer and a decrease in the number of days with extremely low temperatures in winter. Several models suggest an increase in precipitation intensity in some areas, hence the possibility of more extreme precipitation events. Other areas could experience more frequent or severe drought (IPCC 1996).

One of the most certain responses to an increase in average global temperature is an increase in the rate at which global sea level is rising. This would come about largely because seawater expands when warmed. An additional influx of fresh water from melting glacial ice would also add to the oceans' volume. It has been estimated that continued greenhouse warming could cause the world's mean sea level to rise at a rate of 1–11 cm per decade over the next century (IPCC 1996).

Such an increase would expose coastal communities, including many of the world's largest cities, to more frequent and damaging storm flooding and to the salinization of their supplies of fresh water. A number of coastal communities might have to build or extend coastal defensive barriers or engage in other expensive construction projects, such as the relocation of sewer outflows and freshwater intakes. More than 25% of the world's population lives in coastal areas (Hengeveld 1995). Some coastal areas, however, would experience a minimal rise in sea level or none at all, owing to compensating effects such as local upward movement of the Earth's crust caused by postglacial rebound. Central Canada and Scandinavia, for example, have been gradually rising since the end of the last ice age as a result of shedding the great burden of the massive ice sheets. In areas such as Canada's east coast and the Fraser Delta, where the land is subsiding, flooding problems would be aggravated.

Because most plants and animals are adapted to a narrow climatic range, the boundaries of natural ecosystems would change, in some cases considerably, as the Earth warmed. Species stranded outside their normal climatic range would be forced to adapt or migrate in order to survive.

Whereas an average increase in temperature could increase the productivity of certain forests, others would be particularly vulnerable. Trees can migrate naturally only through the spreading of seeds, something that takes considerable time. If the prevailing climate changed too rapidly, large areas of forest could die before new species were able to advance and replace the old. Trees would also be exposed to new insect pests and diseases. Forest dieback, as well as increased drought, would significantly increase loss of forests to wildfires.

Agriculture would also face many of the stresses of natural ecosystems but would be generally less vulnerable, because the possibilities of adaptation through human intervention are greater. Although climate models predict an increase in global precipitation, it would not be evenly distributed. More frequent droughts would likely be the major problem in many areas, especially in the continental interiors of the northern hemisphere.

On the positive side, however, most plants become more efficient at capturing and using moisture when carbon dioxide concentrations increase. They also grow faster and larger if sufficient soil moisture is available. This is known as carbon dioxide fertilization; although some important food crops such as corn and sugarcane do not

respond to it, yields of many other crops could increase significantly. However, a similar response can also be expected for many weed species. For most farmers, crop selection would be the key to successful adaptation. In some areas, this would mean abandoning traditionally successful crops and switching to varieties more suited to the new climatic realities. It is important to note, however, that although warmer temperatures would increase the area of land in Canada with appropriate growing conditions for some crops, much of this new agricultural land would be on marginal agricultural soil.

Many other economic activities could be significantly affected as well. For example, changes in precipitation alone would affect hydroelectric power generation, recreational activities (e.g., skiing), and transportation (e.g., shipping, snow removal). In the Canadian Arctic and sub-Arctic, land transportation would be adversely affected by permafrost decay and a shorter season for winter ice roads. Aboriginal hunting patterns would also be disrupted. On the other hand, warmer winters would reduce the cost of space heating and make these regions more hospitable.

Warmer temperatures could also have an impact on human health in extratropical areas, because tropical diseases and insect pests might extend their range into the middle latitudes. In southern Canada, for example, malaria could become a concern. Warmer temperatures would also intensify the formation of ground-level ozone in smog, as long as other contributing factors did not diminish enough to compensate (see Chapter 10).

Indicators of climate change

Atmospheric scientists are confident that human activity is increasing the concentration of greenhouse gases and that this will affect future climate. What, then, is the corroborating evidence of climate change, and what is the evidence that greenhouse gases are the cause?

The most direct evidence of climate change is found in the world's weather and ocean temperature records over the past century. For the most part, continuous air temperature records based on standardized observations with properly calibrated instruments date back to the latter half of the 19th century. Even then, observations were lacking for most of Asia, much of Africa and South America, and high-latitude areas of both hemispheres. Sea surface temperatures have been measured from ships since the 1850s.

Analyses of these data suggest that air temperatures over the world's land areas have warmed, on average, by slightly more than 0.5°C over the past century (Jones 1994), while the average sea surface temperature has increased by about 0.4°C (Folland and Parker 1995). The few longer air temperature records in existence, which go back as far as the late 18th century, suggest no significant trends prior to 1920. Consistent with model projections, this warming has been weakest in the tropics but considerably stronger in the middle and high latitudes. The greatest warming has occurred in the continental interiors of the northern hemisphere, whereas the coasts have warmed more slowly or even cooled. This pattern appears in the Canadian temperature record: the northwestern interior has warmed by as much as 1.8°C, whereas (over the past 50 years) the eastern Arctic has cooled (see Chapter 10).

A lack of continuous long-term data has hampered the identification of temperature trends in deeper ocean waters. The available short-term records are of limited areal extent, and they do not show a coherent world-wide pattern (IPCC 1996). In the Atlantic Ocean, for example, a warming of 0.2°C has been observed since the late 1950s at a depth of 1 750 m near Bermuda (Levitus et al. 1996), but a cooling of over 1°C was reported in Labrador Sea deep water between the early 1970s and 1990 (Lazier 1996). Such changes seem small, but the top 3 m of the ocean store as much heat as the entire atmosphere. Hence, small changes in this heat storage can significantly affect global climate (Antonov 1990).

As Figure 15.4 shows, the global and Canadian temperature rises of the past century have not been constant. Temperatures increased rapidly during the 1920s and 1930s, then stabilized between the 1940s and early 1970s. Warming resumed in the late 1970s, and above-normal temperatures have continued to the present. In fact, globally, the 10 warmest years since 1860 have all occurred since 1980.

Temperature change has also shown a seasonal bias, at least in the northern hemisphere, with greater warming in winter and spring than in summer and fall (Environment Canada 1995). In the southern hemisphere, there has been much less dif-

Figure 15.4
Global and Canadian air temperature trends over the past century

Source: P.D. Jones and T.M.L. Wigley, University of East Anglia, Norwich, U.K.; Atmospheric Environment Service, Environment Canada

ference in both seasonal and latitudinal warming rates, because of the greater moderating effect of the south's larger ocean area (Manabe and Stouffer 1994).

In many parts of the world, particularly in the northern hemisphere, nighttime temperatures have increased considerably more than daytime temperatures. In the United States, China, and the former Soviet Union, the increase in daily minimum (nighttime) temperatures has been 3–10 times that observed for daily maximum (daytime) temperatures (Karl et al. 1991). In Canada, daily maximum temperatures increased by 0.6°C nationally between 1895 and 1992. Minimum or nighttime temperatures, on the other hand, increased by 1.4°C, more than twice as much over the same period (Environment Canada 1995). One of the implications of warmer nights could be a longer frost-free season for agriculture.

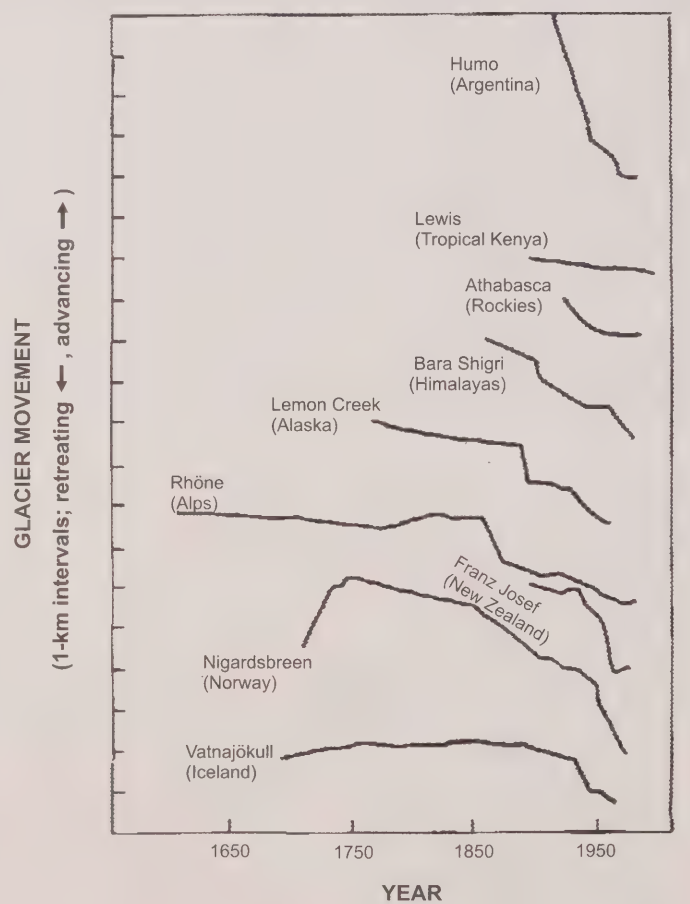
These patterns may provide some insight into how the planet is warming and, in particular, into how feedbacks within the climate system may be modifying any external warming forces. An increase in nighttime cloud cover, for example, would help to explain differences in daytime and nighttime warming rates, because clouds tend to have a net cooling effect by day and a net warming effect by night. Evidence of increased cloud cover during the 20th century has been found over parts of Europe, the United States, Australia, and Canada (Henderson-Sellers 1986, 1989; McGuffie and Henderson-Sellers 1989; Karl and Steurer 1990; Jones and Henderson-Sellers 1992; Environment Canada 1995). However, there are still questions as to whether these increases are real or whether they reflect irregularities in observational records.

Further evidence of widespread warming comes from a variety of temperature-related natural phenomena. Over the past century, the world's mean sea level is estimated to have risen by 10–20 cm, or about 1–2 cm per decade (Warrick and Oerlemans 1990). Although changes for this period are difficult to calculate with much precision, recent satellite measurements, which are highly accurate, show a much larger average rise of 3.9 mm per year during 1993 and 1994 (Nerem 1995). Such a rise could reflect short-term variations in sea surface temperature as well as the longer-term influence of global warming.

Mountain glaciers in most parts of the world have retreated substantially since the latter half of the 19th century (Fig. 15.5). Although glacier development is not solely temperature dependent — precipitation, for example, is another important influence — a global increase in temperature is the most plausible explanation for such widespread glacial retreat.

The percentage of land area that is covered by snow in the northern hemisphere has also shown a modest decline since the early 1970s, a decline that corresponds closely to variations in hemispheric temperature. However, no significant difference in sea ice cover is yet apparent, perhaps because sea ice formation is also strongly dependent on winds and ocean currents as well as

Figure 15.5
Trends in worldwide glacier termini positions



Source: IPCC (1990).

larger patterns of air temperature and runoff changes.

Some parts of the world have shown significant changes in other climatic variables. During the past century, precipitation has increased in the mid-latitudes of the northern hemisphere and throughout most of the southern hemisphere (Bradley et al. 1987; Diaz et al. 1989; Vinnikov et al. 1990). Preliminary studies point to an increase in precipitation over Canada, although there is considerable variation from one region to another (Groisman and Easterling 1994; Environment Canada 1995).

These observations support the conclusion from GCM experiments that increased precipitation would accompany global warming. However, given the observed variability of precipitation from place to place and decade to decade, a long-term trend in global precipitation cannot yet be identified with certainty.

While most of these changes are consistent with those projected by the climate models, none of them actually proves that an enhanced greenhouse effect is the cause. That is because the world's average surface temperature over the past 10 000 years (since the end of the last ice age) has varied over a range of nearly 2°C as a result of purely natural causes. Some 6 000–8 000 years ago, for example, average surface temperatures were about 1°C higher than temperatures in the early 20th century. A thousand years ago, they were a few tenths of a degree higher. Recent temperature changes could, therefore, be wholly or partially the result of natural fluctuations in the climate system. Despite the absence of clear proof, the present scientific consensus is that the broad correspondence between the trends in climate of the past century and their geographical distribution patterns and those projected by models, taken together, point towards a discernible human influence on global climate (IPCC 1996). Finally, it should be noted that if the average global temperature were to rise a further 0.5–1.0°C beyond present-day values, the greenhouse warming hypothesis would almost certainly be confirmed, simply because, of all the possible explanations, greenhouse warming is the only one that could reasonably account for such an increase (Wigley and Barnett 1990; Kerr 1995).

Some other influences on climate

Calculations based on climate model experiments suggest that the planet should have warmed by 0.5–1.0°C over the past century owing to increased concentrations of greenhouse gases. The actual amount of warming measured during this period lies at the very bottom of that range. This could indicate that almost all the models have overestimated the warming effect of a greenhouse gas increase. On the other hand, it could indicate additional forces acting on the climate system that the models have not taken into account. Certainly, natural climate fluctuations continue to occur alongside human-induced warming. These can either reinforce or offset the influence of increased greenhouse gas concentrations. Human-related factors other than an increase in greenhouse gases can have a considerable effect on net warming as well.

One of these factors is the effect of atmospheric aerosols — tiny suspended particles — on solar radiation. Some aerosols, such as coarse particles of soot, provide a direct warming effect in the lower atmosphere by absorbing incoming solar radiation. Others, such as fine sulphates, scatter and reflect incoming sunlight and thus have a direct cooling effect. Sulphate aerosols may also promote cooler surface temperatures indirectly by affecting cloud formation (they provide condensation surfaces for cloud-forming droplets), thereby increasing reflection of solar radiation back to space.

Sulphates form in the atmosphere when sulphur dioxide and other sulphurous gases combine with oxygen. Since the 1860s, sulphur emissions from human sources (mostly the burning of fossil fuels) have increased from less than 3 million tonnes annually to approximately 80 million tonnes in 1980. Originating largely in the industrialized regions of the northern hemisphere, particularly in North America, Europe, and, more recently, China, sulphur emissions have been a focus of attention for some time because of their contribution to acid rain (see Chapter 10).

Current estimates place the direct cooling effect of these sulphates plus fine aerosols from the burning of forests at somewhere between 15% and more than 50% of the total warming effect produced by anthropogenic greenhouse gas emissions. Estimates of their indirect effects fall roughly within the same range (Shine et al. 1995). A cooling effect of this size could have significantly moderated any warming from anthropogenic greenhouse gas emissions. Indeed, models that have been adjusted to take account of aerosol cooling provide good agreement with the observed temperature changes of the past century (Wigley and Raper 1992; Taylor and Penner 1994; Kerr 1995) (Fig. 15.6). However, human-produced aerosols should not be considered as a simple counterweight to increased greenhouse gas concentrations. Unlike greenhouse gases, they are not spread evenly around the globe, and they have a relatively short residence time in the atmosphere.

Human-produced aerosols have a substantial effect on incoming solar energy within a few thousand kilometres downwind of the industrialized areas of the northern hemisphere. Thus, some regions actually show cooling as a result of these aerosols (Kerr 1995). These regional changes can also significantly influence large-scale atmospheric properties such as circulation patterns, thereby causing substantial indirect effects in many other parts of the world. Their effect on the climate system as a whole is therefore very complicated (IPCC 1995).

Natural sulphate aerosols from large volcanic eruptions are also known to have a cooling effect, but only for one or two years, as was the case after the eruption of Mount Pinatubo in the Philippines in the summer of 1991. The cooling effect of these aerosols — estimated at about 0.3–0.5°C during 1992 (IPCC 1995) — was itself largely offset by a prolonged El Niño (the periodic warming of the equatorial Pacific) that matured late in 1991 and continued well into 1992.

Some researchers have also attempted to link temperature changes over the past few centuries to changes in the output of solar radiation. It has been postulated, for example, that variations in solar radiation could have contributed to the medieval warm period and the Little Ice Age (the period between about 1550 and 1850). During the latter period, average global temperature was as much as 1°C below present values, and mountain glaciers advanced in most parts of the world (Eddy 1977). However, estimates of solar activity over the past century suggest that increased solar output has only had a minor warming effect — equivalent to a little more than 10% of that from the increase in greenhouse gases (Shine et al. 1995).

Another mechanism that may influence the global temperature record is the possible presence of more or less regular, natural oscillations in the climate system. These occur in interannual, decade-to-century, and even longer time scales, determined by various internal modes of oscillation in ocean circulation (e.g., Philander 1990; Weaver et al. 1994). Through heat exchange with the atmosphere, these modes can produce what appear to be long-term variations in air temperature that could help to explain the Little Ice Age or the medieval warming (Stocker and Mysak 1992; Mysak et al. 1993). One group of researchers (Schlesinger and Ramankutty 1994), for example, claims to have detected a 65- to 70-year oscillation in northern hemisphere temperatures that is of sufficient size to obscure evidence of greenhouse warming in the global temperature record over the past century. However, because reliable estimates of air temperature do not extend back farther than the mid-19th century, it is impossible to verify whether these oscillations are a permanent feature of the climate system.

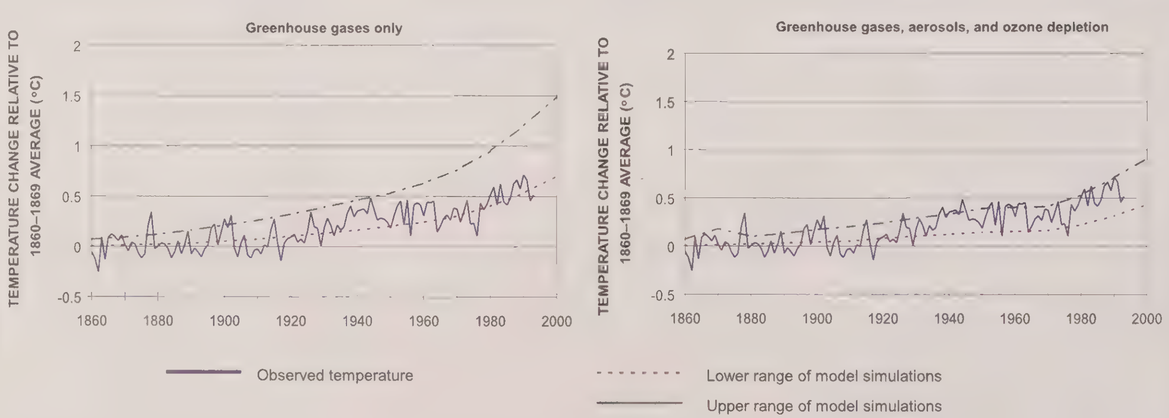
The greenhouse effect in the future

When the forces of change that have been acting on the climate system over the past 150–250 years are compared, as in Figure 15.7, it is apparent that anthropogenic greenhouse gas emissions are considerably more powerful than any of the other factors. There is also no doubt that, as concentrations of these gases increase, their warming influence will become even stronger.

As of the end of 1993, average global carbon dioxide concentrations were about 28% above the preindustrial level. If other greenhouse gases are taken into account, the combined increase in their concentrations by the end of 1990 was already equivalent to a 50% increase in carbon dioxide (IPCC 1995). What happens to greenhouse gas concentrations after this depends on future levels of emissions. These, in turn, depend on the complex interplay of social, economic, and technological factors. Future population growth, economic growth, and deforestation rates are the most important factors contributing to future increases in greenhouse gas concentrations, but these increases could be offset by factors such as higher energy prices, improvements in energy efficiency, the availability of practical alternatives to fossil fuels, and the development of policies and controls for regulating emissions of greenhouse gases and preserving reservoirs of carbon.

Even if emissions of carbon dioxide could be held at 1990 levels, atmospheric concentrations would continue to rise, reaching 450 ppmv (about 60% higher than preindustrial levels) by 2050 and 520 ppmv (about 85% higher) by 2100. In other words, given current trends, a doubled carbon dioxide atmosphere appears inevitable unless more progress is made in controlling these emissions. However, with a growing global population (90 million people — *over three times the population*

Figure 15.6
Observed and modelled global temperature trends



Source: Wigley and Raper (1992).

of Canada — are added every year) and the awakening of potentially massive economies such as those of China and India, the upward pressure on greenhouse gas emissions will be formidable. Even with substantial improvements in energy efficiency and in the availability of economically viable alternative energy sources, the world community must be vigilant in assessing progress towards stabilization and must fully consider the economic, social, and environmental dimensions of the issue.

In its 1992 report, the IPCC presented six different scenarios of socioeconomic change and calculated their impact on future greenhouse gas emissions and global temperatures (Leggett et al. 1992). Table 15.5 summarizes the key assumptions of each of the scenarios, and Figure 15.8 shows their effect on carbon dioxide emissions and consequent atmospheric concentrations of carbon dioxide. It is important to remember, however, that these are not predictions of the future, but simply indicators of how emissions are likely to respond to key variables, particularly population and economic growth.

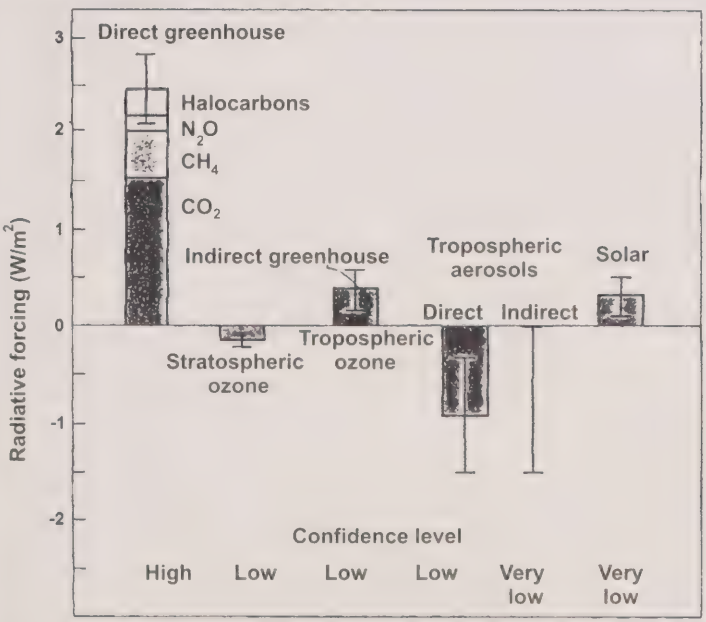
The middle-range scenario, IS92a, assumes no radical changes in present economic and population trends and can be thought of as a business-as-usual scenario. It also assumes a gradual phaseout of CFCs and reductions in emissions of some common air pollutants, but no controls on carbon dioxide. Under this scenario, carbon dioxide emissions would grow from their present estimated level of about 7.5 billion tonnes per year to 12.2 billion tonnes by 2025 and 20.3 billion tonnes by 2100. This would lead to a doubling of atmospheric carbon dioxide concentrations shortly after 2050. If a doubling of carbon dioxide leads to an eventual global average temperature increase of somewhere between 1.5°C and 4.5°C, as the models suggest, then global temperatures could increase by 2–4°C by the end of the next century, even without increases in other greenhouse gases such as methane and nitrous oxide. Interestingly, current commitments by the developed industrialized countries to stabilize or moderately reduce carbon dioxide emissions, which are considered in scenario IS92b, would have only a small effect on these outcomes (Mitchell and Gregory 1992).

A number of other factors — both natural and human — could also affect changes in greenhouse gas concentrations and global temperatures. Emissions of sulphate aerosols from human activities and volcanic eruptions have the most immediate significance because of their relatively large impact on surface air temperature. Over the next decade, further reductions in sulphur emissions from industrialized countries of Europe and North America (currently the world's principal emitters) can be expected. However, these reductions may well be offset by increases in sulphur emissions from developing countries, particularly China, which relies on its large coal reserves to meet its rapidly expanding requirements for energy. Using the growth assumptions of the IPCC's IS92a scenario, global sulphur emissions from human sources could rise from the present level of about 75 million tonnes to 147 million tonnes by 2100 (Leggett et al. 1992).

Finally, there are uncertainties about the size and future behaviour of some of the natural sinks that remove greenhouse

Figure 15.7

Estimated amounts of radiative forcing attributable to greenhouse gases and aerosols from preindustrial times to the present, and observed changes in solar radiation since 1850 (globally averaged)



Notes: 1. "Radiative forcing" is the term used to denote the power of radiant energy received over a given area expressed in watts per square metre (W/m^2). For example, the radiative forcing of total incoming solar radiation at the top of the Earth's atmosphere, averaged around the globe, is 343 W/m^2. Of that amount, an average of 103 W/m^2 is reflected back to space by the Earth's atmosphere and surface, leaving an average of 240 W/m^2 to drive the climate system.

2. The height of the rectangular bar indicates the mid-range estimates of the forcing, whereas the error bars show an estimate of the uncertainty. The subjective confidence that the actual forcing lies within this error bar is indicated by the "confidence level" along the bottom of the graph.

Source: IPCC (1995).

gases from the atmosphere. For example, the rate of growth of methane concentrations decreased from about 1.3% per year in the late 1970s to virtually zero in 1992 (although some increase in the growth rate was seen again by late 1993). This change is not yet understood. Over the longer term, there are questions about the continuing ability of the oceans and terrestrial ecosystems to absorb, as they do now, nearly half the carbon dioxide emitted by human activities.

A variety of unexpected feedbacks could affect the pace and character of climate change as well. The polar regions, for example, contain an estimated one million trillion to one billion trillion tonnes of methane locked away in frozen hydrates (Judge and Majorowicz 1993). If large areas of permafrost were to thaw, some of this gas could be released and would result in a substantial intensification of the greenhouse effect. Studies of the latter part of the last ice age 10 000–15 000 years ago (Broecker and Denton 1990) and of the preceding interglacial period approximately 125 000 years ago also indicate that ocean circulation patterns can undergo abrupt changes, leading to dramatic shifts in regional climates within a few decades.

Actions to control greenhouse gas emissions

That anthropogenic greenhouse gas emissions present a very real risk of climate change has largely been recognized by the world community and has led to the drafting of the United Nations Framework Convention on Climate Change (FCCC). Signed by more than 150 nations at the 1992 Rio Earth Summit, the FCCC calls for the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." It does not set any specific goals for achieving this objective, but it does state as a general principle that "such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner."

As a first step towards achieving this objective, most industrial countries have made commitments similar to Canada's commitment to stabilize net greenhouse gas emissions (other than those covered by the Montreal Protocol) at 1990 levels by the year 2000. To meet these targets, most countries are looking at a variety of mea-

Table 15.5
Summary of assumptions in the six IPCC scenarios

Scenario	Population (billions)	Economic growth	Energy supplies	Other	CFCs
IS92a	World Bank (1991) 11.3 by 2100	1990–2025 2.9% 1990–2100 2.3%	12 000 EJ conventional oil 13 000 EJ natural gas Solar costs fall to \$0.075/kWh 191 EJ of biofuels available at \$70/barrel[a]	Legally enacted and internationally agreed controls on SOx, NOx, and NMVOC[b] emissions Efforts to reduce emissions of SOx, NOx, and CO in developing countries by middle of next century	Partial compliance with Montreal Protocol. Technological transfer results in gradual phaseout of CFCs in nonsignatory countries by 2075
IS92b	World Bank (1991) 11.3 by 2100	1990–2025 2.9% 1990–2100 2.3%	Same as in IS92a	Same as in IS92a plus commitments by many OECD[c] countries to stabilize or reduce CO_2 emissions	Global compliance with scheduled phaseout of Montreal Protocol
IS92c	UN[d] medium-low case 6.4 by 2100	1990–2025 2.0% 1990–2100 1.2%	8 000 EJ conventional oil 7 300 EJ natural gas Nuclear costs decline by 0.4% annually	Same as in IS92a	Same as in IS92a
IS92d	UN medium-low case 6.4 by 2100	1990–2025 2.7% 1990–2100 2.0%	Oil and gas same as in IS92c Solar costs fall to \$0.065/kWh 272 EJ of biofuels available at \$50/barrel	Emission controls extended worldwide for CO, NOx, NMVOC, and SOx Deforestation halted. Capture and use of emissions from coal mining and gas production and use	CFC production phaseout by 1997 for industrialized countries Phaseout of HCFCs
IS92e	World Bank (1991) 11.3 by 2100	1990–2025 3.5% 1990–2100 3.0%	18 400 EJ conventional oil Gas same as in IS92a Phase out nuclear by 2075	Emission controls that increase fossil energy costs by 30%	Same as in IS92d
IS92f	UN medium-high case 17.6 by 2100	1990–2025 2.9% 1990–2100 2.3%	Oil and gas same as in IS92e Solar costs fall to \$0.083/kWh Nuclear costs increase to \$0.09/kWh	Same as in IS92a	Same as in IS92a

[a] Approximate conversion factor: 1 barrel = 6 GJ.
[b] NMVOC = nonmethane volatile organic compounds.
[c] OECD = Organisation for Economic Co-operation and Development.
[d] UN = United Nations.

Source: Adapted from Leggett et al. (1992).

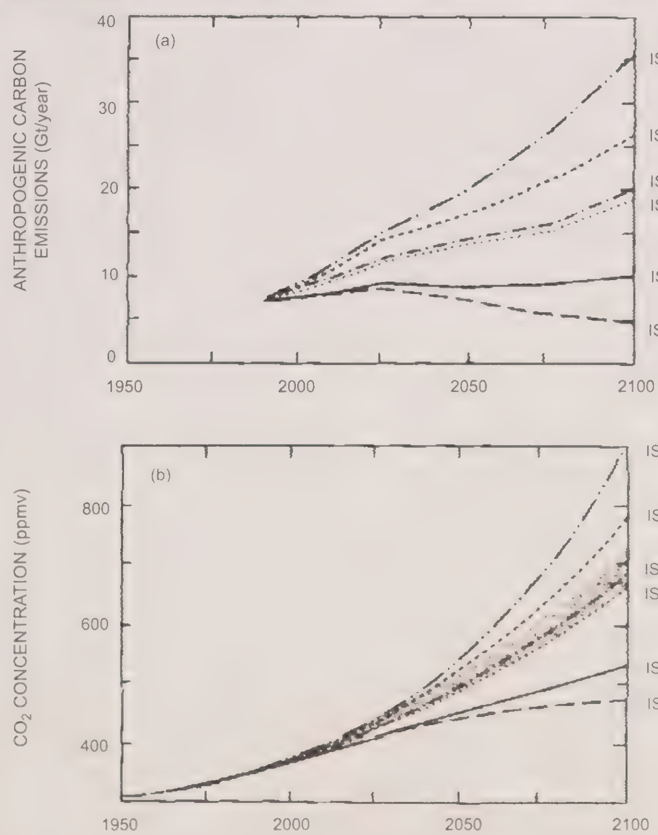
sures, but moderation of energy demand through more efficient use of energy has received the most emphasis. The replacement of high-carbon fuels such as coal and gasoline with alternatives such as propane, natural gas, and gasohol (ethanol- or methanol-blended gasoline) is also being promoted by many countries, in some cases with economic incentives or carbon taxes being used to influence consumer behaviour. Some countries, such as France and Japan, propose to increase their reliance on nuclear energy, whereas others, such as Germany and Denmark, intend to increase the use of renewable energy sources, such as wind-generated and solar power. However, there are economic, technical, and political limits to the degree to which renewables can be substituted for fossil fuels.

Canada's National Action Program on Climate Change (CCME 1995) presents a range of largely voluntary measures for achieving the stabilization of greenhouse gas emissions. Most of these measures are detailed and sector specific, making it possible to relate actions directly to individual emission sources. Among the program's options are the development of incentives, regulations, and technical training to improve energy efficiency in both the residential and commercial sectors; altered subsidies in the energy, transportation, agriculture, and forestry industries; and measures to encourage the use of more fuel-efficient cars. Agricultural practices that would reduce soil carbon loss (and hence greenhouse gas emissions) include increased use of conservation tillage practices and reduced use of summerfallow. Measures that would foster increased carbon sequestration include increased cultivation of forage crops and further improvements in crop yields. The program also promotes the development of new forests to increase the removal of carbon dioxide from the atmosphere. Underlying the National Action Program is the principle — the precautionary principle — that where there are threats of serious or irreversible damage to our health and livelihood, lack of scientific certainty should not be used as a reason for postponing mitigative actions (see Chapter 1, Box 1.7).

As of October 1995, the federal government also had 37 initiatives under way as part of its Efficiency and Alternative Energy Program to improve energy efficiency and the use of alternative energy in Canada, thereby limiting greenhouse gas emissions. A number of these focus on improving end-use efficiency through improvements to equipment and appliances, building structures and fittings, industrial processes and machinery, and motor vehicles and transportation systems. Others are promoting the development and use of low-carbon transportation fuels, noncarbon fuels such as hydrogen, and renewable energy sources such as biomass, wind, and solar power. Communities and public utilities are also being encouraged to place greater emphasis on demand management, cogeneration (use of a fuel for both electricity and useful heat), and district heating. Further support for the limitation of greenhouse gas emissions is provided by other federal programs, such as the National Action Program's recently announced Voluntary Challenge and Registry Program, which invites Canadian companies and organizations to develop

Figure 15.8

Annual human-related carbon dioxide (as carbon) emissions and resulting atmospheric concentrations of carbon dioxide for the six IPCC scenarios



Note: Shaded area in (b) represents the range of results from different models for the IS92a scenario.

Source: IPCC (1995).

action plans to limit net greenhouse gas emissions. In addition, there are various provincial/territorial and municipal initiatives. Provincial and territorial jurisdictions have developed their own climate change action plans, which they tabled at a meeting of Environment and Energy ministers in November 1995. Several Canadian municipalities intend to reduce greenhouse gas emissions by 20% of 1988 baseline levels by 2005. These municipalities have formed the "Twenty Percent Club" to share cost-effective strategies for mitigation.

In spite of these programs, stabilizing Canada's greenhouse gas emissions at 1990 levels will not be easy. Without significant action under the Voluntary Challenge and Registry Program and additional government measures under the National Action Program, energy-related emissions will likely increase by 13% over 1990 levels by the year 2000, as a result of normal population and economic growth alone (CCME 1995). Whether present, largely voluntary measures are sufficient to forestall such an increase is an open question, but there should be a clearer indication of their effectiveness, and of any need for additional measures, by the end of 1996, with the first progress review under the National Action Program.

Developing countries will face even greater difficulties in restraining the growth of their greenhouse gas emissions. Although currently minor producers of greenhouse gases, many of these countries are rapidly increasing their use of fossil fuels. Energy use in some of these countries could grow by as much as 5–7% *per year* over the next 30 years (Churchill 1993). Consequently, today's developing countries are expected to account for more than half of all energy-related greenhouse gas emissions by the middle of the next century, compared with about a third at present. To meet their commitments under the FCCC while maintaining an adequate pace of economic development, most will require support from the developed countries. This will primarily take the form of capital and technology transfers to assist the development of high-efficiency, low-emission facilities and infrastructure.

A large part of the current emissions of carbon dioxide from deforestation originates in developing nations. Tropical forests have been destroyed not only to meet increasing local demands for fuel and timber and make more land available for agriculture, but also to satisfy demands of the industrialized countries for forest and agricultural products. A 1988 survey of 18 member states of the International Tropical Timber Organization reported that *less than 1%* of their harvesting areas were being logged sustainably (World Resources Institute 1990). Better management practices must be developed to protect existing forests, and replanting on a large scale must be encouraged, both to support future sustainable use and to restore the effectiveness of tropical and temperate forests as carbon dioxide reservoirs.

As noted above, even if all the nations of the world were to stabilize their emissions at 1990 levels, greenhouse gas concentrations in the atmosphere would still continue to rise. To stabilize atmospheric concentrations near present levels, it would be necessary to make far deeper cuts in greenhouse gas emissions. For carbon dioxide alone, these would amount to about a 40–60% reduction in present global emissions (IPCC 1990).

Some of the technology for a low-carbon economy already exists, at least in prototype form. Most major car manufacturers, for example, have developed experimental vehicles that can travel 100 km on about 3 L of fuel. Cars using such innovations as ultralight carbon fibre bodies, ceramic engines, and hybrid propulsion systems that combine heat engines and electric motors could triple this performance (Lovins and Lovins 1995). Some alternative technologies, such as those for using hydrogen fuels, need much more development before they are commercially practical, but others, such as solar power, are now nearing the point of commercial viability in some parts of the world. California already has several hundred megawatts of solar-thermal generating capacity, and Nevada will shortly be receiving power from a 100-MW solar generator using photocell technology.

As even an immediate stabilization of anthropogenic greenhouse gas emissions will not halt the growth of greenhouse gas concentrations in the atmosphere or prevent at least some further warming, adaptation strategies are also included in Canada's National Action Program on Climate Change. Like energy efficiency measures that reduce greenhouse gas emissions, adaptation strategies can offer other returns that make them worth doing anyway. In agriculture, for example, vulnerability to climate change can be reduced by avoiding monocropping and selecting crops or species that demand less water. In forestry, consideration can be given to strengthening fire and pest monitoring and intensifying firefighting. Other economic sectors in which adaptation can play a major role include fisheries, construction, and energy supply (Task Force on Climate Adaptation 1993).

With competing pressures from economic concerns and continuing uncertainty about the extent of human-induced global warming, it is hard to generate a sense of urgency about climate change. Yet many of the initial steps to reduce greenhouse gas emissions, such as improving energy efficiency, produce other environmental and economic benefits. This is fortunate, because the climate change issue is indeed urgent, and the underlying scientific arguments are compelling.

Stratospheric Ozone Depletion

The ozone layer

Ozone is found throughout the atmosphere, but most of it (about 90%) occurs in the stratosphere at altitudes of 18–35 km — the "ozone layer" (Fig. 15.9). The maximum ozone concentration within this band is between 20 and 25 km above the Earth's surface (WMO 1994). Yet, even in the stratosphere, ozone molecules are scattered so thinly that, if compressed, they would form a band of pure ozone only 3 mm thick at sea level. This is equivalent to 300 Dobson units (DU), the unit usually used to measure the thickness of ozone in the atmosphere. One DU is equivalent to a

layer of pure ozone 0.01 mm thick at standard temperature (15°C) and pressure (101.3 kPa), spread over the surface of the Earth.

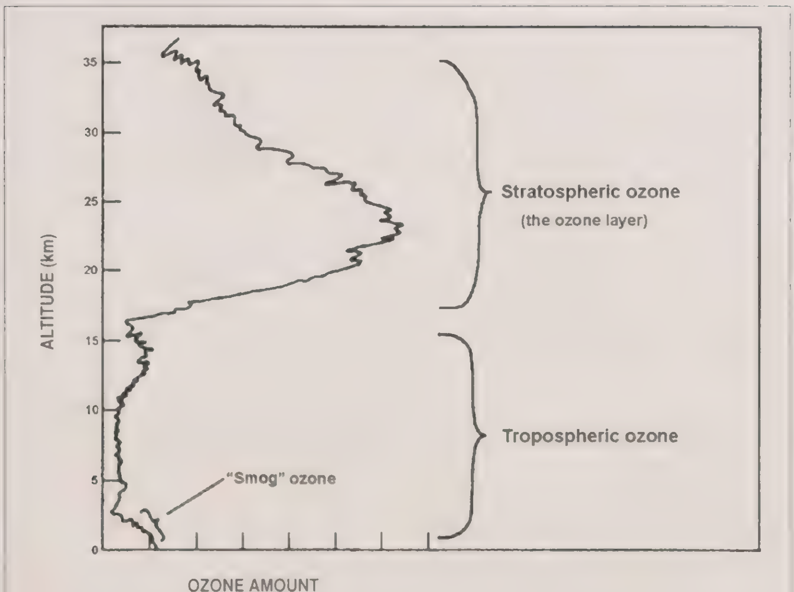
Stratospheric ozone is produced by the effect of highly energetic ultraviolet radiation on molecular oxygen. Although it is readily destroyed when it leaves the stratosphere and enters the lower part of the atmosphere (troposphere), most of the globe's ozone remains in the stratosphere, where it acts as a shield against this harmful radiation. This protective shield, however, is being compromised by a number of human-made substances that destroy stratospheric ozone. Owing to an unprecedented worldwide response, many of these now fall under strict control, but their effects will be felt for some time to come. (Ground-level ozone, a component of smog, is addressed in Chapter 10.)

In the stratosphere, ultraviolet radiation causes the two atoms of molecular oxygen (O_2) to split apart. When a freed oxygen atom collides and unites with an oxygen molecule, an ozone molecule (O_3) is formed. However, ozone is also broken down by sunlight and by chemical reactions with various naturally occurring, although relatively scarce, substances that contain nitrogen, hydrogen, chlorine, or bromine. Thus, in a normal, unperturbed atmosphere, the amount of ozone produced in the stratosphere is balanced over time by the amount destroyed.

Ozone is not distributed evenly around the globe. It is produced in largest quantities near the equator, where sunlight is most direct and intense. Some of that ozone is transported poleward by stratospheric winds, to the extent that ozone thicknesses can be 50% greater at mid- and higher latitudes than in the tropics.

There are also seasonal variations in ozone thickness over the Earth. For example, the poleward transport of ozone is most significant in winter. With little or no ozone-destroying sunlight available at that time of year, stratospheric ozone increases in polar areas, peaking near the end of the cold season (February in the northern hemisphere). As spring approaches and sunlight intensifies, ozone depletion resumes and continues through the summer. Over Canada, therefore, lowest ozone thicknesses are usually recorded in the summer and fall. In tropical latitudes, where the input of solar energy is more constant from season to season, ozone variations are much smaller.

Figure 15.9
Distribution of ozone in the atmosphere



Source: After WMO (1994).

Depletion of the ozone layer

A human role in the depletion of the ozone layer — first raised as a possibility in the 1960s — has been firmly established during the past decade. Stratospheric ozone depletion has been linked primarily to CFCs, the family of stable, nontoxic, nonflammable, highly versatile chemicals first developed in the 1890s and increasingly used over the past several decades as spray propellants, refrigerants, foam-blowing agents, solvents, and cleaning fluids.

Because of their chemical stability, CFCs can survive in the atmosphere for several decades to a few centuries. This allows them to diffuse gradually from the troposphere into the stratosphere, where they are eventually broken down by intense ultraviolet radiation, releasing chlorine atoms that react readily with ozone to produce chlorine monoxide and oxygen (Fig. 15.10). The chlorine monoxide, however, breaks down quickly, leaving its chlorine atom free to combine again with another molecule of ozone. In this way, a single atom of chlorine may destroy hundreds of thousands of ozone molecules before finally forming a more stable combination with another substance.

CFCs are not the only ozone-depleting chemicals produced by human activities, but they are the most abundant. CFC-11 and CFC-12 together account for about half of the ozone-depleting chlorine entering the stratosphere (WMO 1994). Other important ozone-depleting chemicals include HCFCs, carbon tetrachloride, and methyl chloroform, all of which contain chlorine. Of the bromine compounds, the most significant are the halons (used in

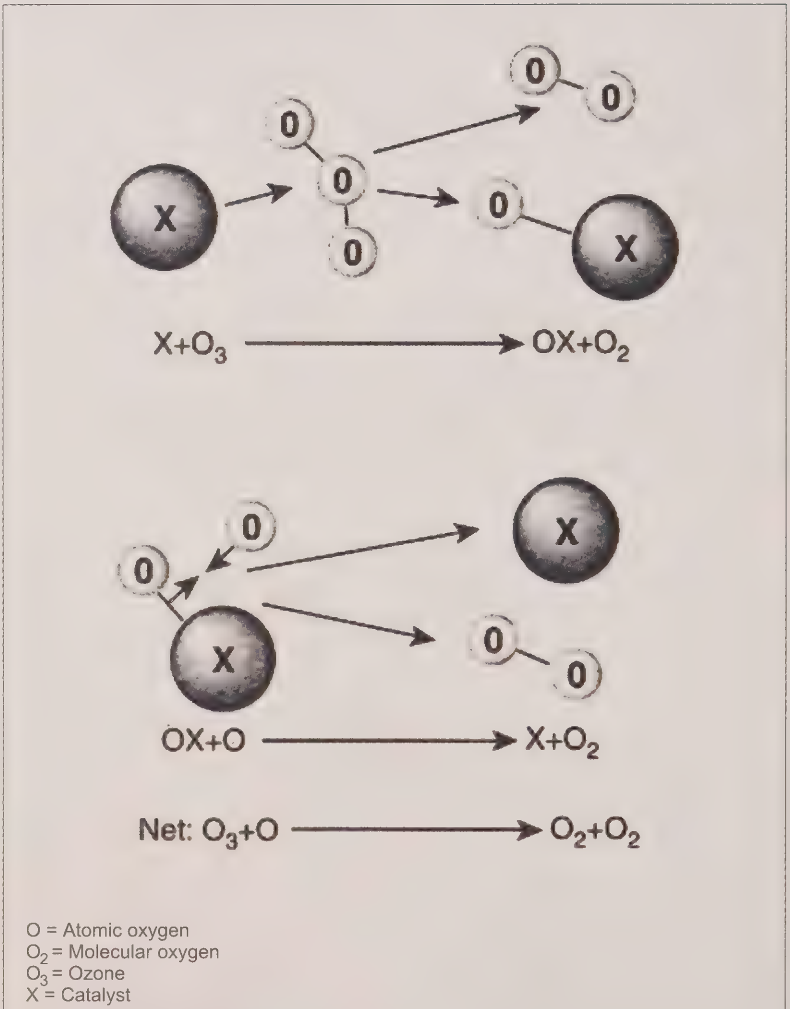
fire extinguishers) and methyl bromide (an agricultural fumigant). Unlike other ozone-depleting chemicals, methyl bromide has a relatively short lifetime. Bromine is, however, highly effective in removing ozone, and methyl bromide is therefore considered to be a significant contributor to ozone depletion. Because of the short lifetime of methyl bromide, reductions in its consumption would have a more immediate effect on reducing ozone depletion than would reductions of longer-lived substances.

Ozone-depleting chemicals have the least effect on tropical ozone levels, because the rate of natural replenishment of ozone at low latitudes is high. In mid-latitudes, however, depletion of the ozone layer has been more noticeable since the 1970s. Figure 15.11, based on measurements taken from satellites, shows that average ozone concentrations over the mid-latitudes of the northern hemisphere (including much of North America, Europe, and Asia) have declined by about 7% since 1978. The considerable interannual variability in ozone amounts, due primarily to periodic variations in stratospheric wind patterns, can also be clearly seen in the graph.

The most dramatic depletion of the ozone layer occurs over the Antarctic during the southern spring and lasts for about two months, producing the noted "ozone holes"[3] that have been observed every year since they were first reported in 1985. The depletion of Antarctic ozone depends on two unique events that occur in the southern polar region during winter. The first is the polar vortex, a closed circulation of air around the south pole that develops in the stratosphere with the onset of polar night, partially isolating the polar air mass. The second is the formation of polar stratospheric clouds (PSCs), which occurs at the extremely low temperatures (below –78°C) that develop within this vortex as it matures and cools in the absence of heating by sunlight or by the influx of warmer air from lower latitudes. Ice crystals in these clouds provide a medium for a complex variety of chemical reactions that lead to the rapid depletion of ozone when sunlight returns in the spring. At the same time, the polar vortex prevents the replenishment of the lost ozone by air from the tropics. It is only when the vortex breaks down later in the spring that the transport of ozone into the polar stratosphere can begin again.

In addition, chemical processes that destroy ozone may occur on the surfaces of volcanic aerosols in the stratosphere. Although these have little additional effect on the scale of ozone depletion over the Antarctic at present, they appear to have intensified ozone depletion in the mid-latitudes and the Arctic. The unusually severe depletion of early 1993 shown in Figure 15.11, for example, has been attributed to the presence of aerosols from the eruption of Mount Pinatubo, plus an increased isolation of the Arctic vortex from surrounding air masses (Manney et al. 1994).

Figure 15.10
Ozone destruction by catalysts



Source: Hengeveld (1995).

3. The expression "ozone hole" is somewhat misleading. It suggests that ozone is absent, when in fact it is still present, although in reduced amounts. "Thinning" or "depletion" of the ozone layer is a more accurate way of describing the situation.

In the Antarctic, the depletion of ozone in the stratosphere has become more pronounced over time. In 1989, the area of serious depletion (defined here as the area in which total ozone thickness was less than 220 DU) covered about 7.5% of the southern hemisphere, and ozone thicknesses as low as 111 DU were recorded. In October 1993, ozone thicknesses as low as 91 DU were recorded over the Antarctic (Hofman et al. 1994) (Fig. 15.12). In 1993 and 1994, ozone depletion reached its largest extent yet, the area of reduced ozone covering about 10.7% of the southern hemisphere (about the size of North America) (WMO 1994). Although the area of depletion was no greater in 1995, ozone loss started earlier than usual, and the area affected expanded more rapidly than in previous years (WMO 1995).

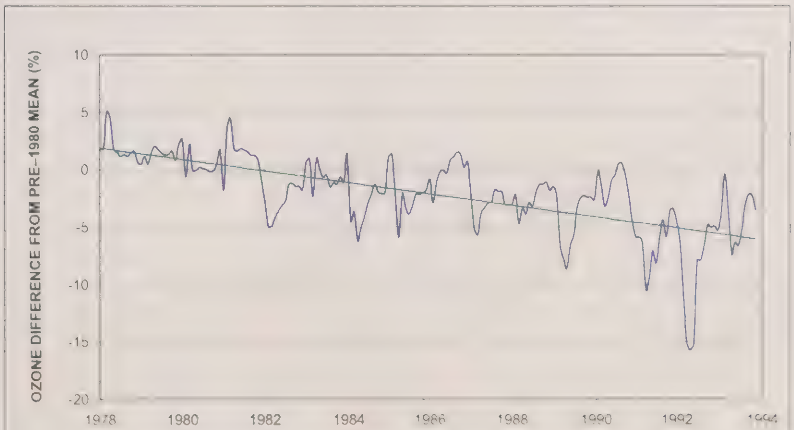
Ozone depletion comparable to that over the Antarctic has yet to occur over the Arctic. Major Arctic ozone depletion is less likely to occur, because the Arctic vortex is much less stable than its southern counterpart and breaks up sooner. The Arctic stratosphere is also slightly warmer and therefore less conducive to PSC formation. However, if, as predicted, the stratosphere cools as a result of an enhanced greenhouse effect, the conditions for PSC formation would improve, increasing the possibility of more pronounced Arctic depletions.

Ultraviolet radiation and its impacts

Ultraviolet (UV) radiation is an energetic component of sunlight. When sufficiently intense, it can break stable chemical bonds and damage deoxyribonucleic acid, or DNA, the genetic coding material that living things carry in their cells.

The longest and least powerful wavelengths of ultraviolet radiation are known as UV-A. These pass through the atmosphere almost as easily as visible light but are relatively harmless to most organisms within the normal range of intensity. A small proportion of the middle (UV-B) wavelengths also reach the Earth's surface. These rays are more powerful than UV-A and can cause biological damage to plants and animals. The shortest and most biologically harmful ultraviolet wavelengths, known as UV-C, are almost completely absorbed in the upper atmosphere and do not reach the Earth's surface.

Figure 15.11
Total ozone trend, 30–65°N



Source: National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (personal communication); Atmospheric Environment Service, Environment Canada (personal communication).

The total amount of ultraviolet radiation reaching the Earth's surface depends on several factors — the angle of the sun, the amount and type of cloud, the presence of atmospheric aerosols, and the thickness of the ozone layer. Ozone absorbs almost all of the very harmful UV-C and most UV-B. It is therefore one of the two most important determinants of how much UV-B radiation reaches the Earth's surface, the other being clouds.

Under clear skies in the mid-latitudes, a 1% decrease in the thickness of the stratospheric ozone layer results in about a 1.1–1.4% increase in UV-B radiation at ground level (McElroy et al. 1994). During winter and spring, the resulting increase in UV-B at the Earth's surface is moderated by the lower angle of the sun. At a mid-latitude location such as Toronto, the additional UV-B intensity in winter and spring is still lower than normal summer values.

About half the 200 species of crops and trees in Canada are sensitive to the increased levels of UV-B expected in the next decade. Many plants show reduced photosynthesis and growth when their exposure to UV-B is increased. However, responses vary widely from species to species and even among different varieties within a single species.

For humans, sunburn is the most immediate response to excessive exposure to UV-B radiation. However, eye cataracts and skin cancers can also develop with repeated exposure to these damaging rays. There is also evidence that excessive UV-B exposure can decrease the efficiency of the body's immune system, which could lead to an increase in some types of infectious diseases and render some vaccination programs less effective.

Linking an increase in UV-B intensity to human health effects, however, is extremely difficult, mainly because ozone-related impacts cannot be easily distinguished from those caused by other factors. The long incubation period for some cancers is another complicating factor. The occurrence of skin cancers in Canada has increased rapidly over the past two decades, but this could reflect lifestyle

choices, such as the growing popularity of sunbathing or tropical holidays, rather than increases in UV-B intensity caused by the thinning of the ozone layer.

Organisms in natural ecosystems, with a more limited repertoire of behavioural options, may provide less ambiguous evidence of ultraviolet radiation damage related to ozone depletion. Phytoplankton and zooplankton, the tiny plants and animals that live in the surface layers of lakes and oceans, are considered to be the most vulnerable life-forms because of their relatively direct exposure to the sun.

Antarctic phytoplankton could be particularly at risk, because their blooms begin to develop just as ozone thinning is occurring. One study, undertaken at the time of the 1990 ozone event, estimated that phytoplankton productivity was 6–12% lower within the zone of ozone depletion than beyond it (Prézelin et al. 1994). As yet, however, there is no evidence of a major decline in Antarctic phytoplankton populations. Elsewhere, increased UV-B intensity may be contributing to the mysterious decline in frog and toad populations in many parts of the world (Blaustein et al. 1994).

The response of different organisms to increases in UV-B could also be affected by ecological interactions. During experiments to study the effects of ultraviolet radiation on algae, it was noted that algal populations that had at first declined when exposed to UV-B gradually rebounded when the exposure was continued. Further research showed that populations of midge larvae (chironomids) that fed on the algae were affected even more strongly by the radiation. As the chironomid population declined, grazing pressure on the algae was reduced, and the algal community expanded (Bothwell et al. 1994).

Research results so far suggest that the effects of increased ultraviolet radiation on natural populations are likely to be complex and selective. Consequently, there may be no simple model for predicting the ecological impacts of increased ultraviolet radiation, and the effects may vary widely from one ecosystem to another.

Actions to control depletion of the ozone layer

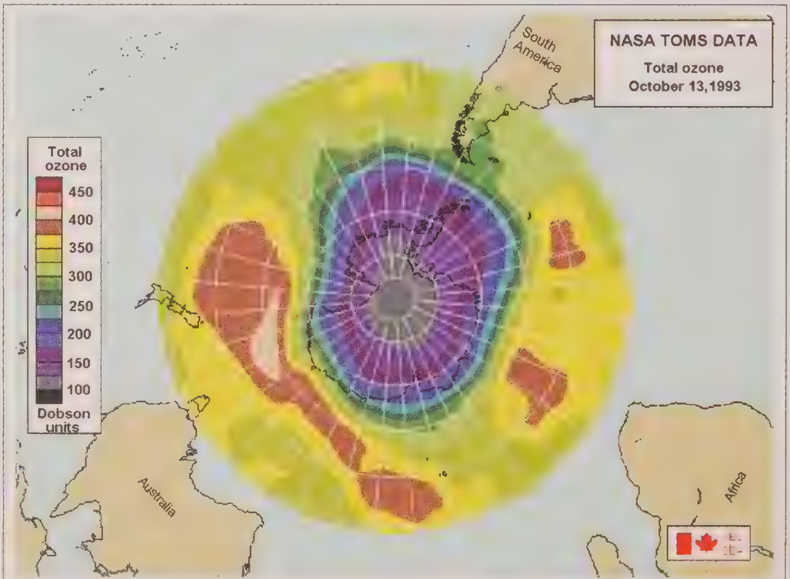
Under the Montreal Protocol of 1987, the major industrialized nations agreed to cut their consumption of CFCs in half by mid-1999 and to freeze their consumption of halons at 1986 levels by early 1992. Developing countries that signed the agreement were given an additional 10 years to meet these targets.

At a meeting in London in 1990, the international community agreed to virtually eliminate the consumption of these compounds by the year 2000. At the same time, methyl chloroform and carbon tetrachloride were added to the list of controlled substances.

Further amendments agreed to at Copenhagen in 1992 added methyl bromide, HCFCs, and hydrobromofluorocarbons (HBFCs) to the controlled list and brought forward the phaseout dates to 1996 for CFCs and to 1994 for halons. By September 1995, 149 countries had ratified the Montreal Protocol, 102 had ratified the London amendments, and 47, including Canada, had ratified the Copenhagen terms. In December 1995, in Vienna, the Parties to the Montreal Protocol further adjusted the control measures for HCFCs and methyl bromide. The major controlled substances and their phaseout dates under the Montreal Protocol, the London and Copenhagen amendments, and the Vienna adjustments, as well as the corresponding Canadian position, are shown in Table 15.6.

Canada has a National Action Plan for the Recovery, Recycling and Reclamation of CFCs. Federal and provincial governments, in cooperation with the Heating, Refrigeration and Air Conditioning Institute and municipalities, have developed a training program on the proper handling, recovery, and recycling of CFC refrigerants. Over 60 000 technicians have been trained. Most CFC uses, other than refrigeration and air conditioning, have been eliminated, and "CFC-free" refrigerators are being introduced.

Figure 15.12
Total ozone over the southern polar region, October 13, 1993



Source: National Aeronautics and Space Administration (NASA)/Goddard Space Flight Center (personal communication); Atmospheric Environment Service, Environment Canada (personal communication).

As a direct result of international agreements, the last few years have seen a dramatic decline in the production and consumption of ozone-depleting substances. For the world as a whole, new supplies of CFCs have declined from a peak of 1 260 000 t in 1988 to 510 000 t in 1993. Because these substances may take several years to penetrate the stratosphere (and because most of them do not escape into the atmosphere until well after they have been manufactured), atmospheric concentrations of these chemicals are still rising, but the rate of increase of several major ozone-depleting substances (e.g., CFC-11 and CFC-12) has begun to slow (Fig. 15.13). Equivalent stratospheric chlorine concentrations resulting from these and other ozone-depleting chemicals are expected to peak near the end of the century and then decline (WMO 1994).

Over the past century, the abundance of chlorine in the stratosphere has increased from an estimated natural background level of about 0.6 parts per billion (ppb) to about 3.6 ppb in 1994. It is expected to reach 4.1 ppb around the turn of the century before slowly declining in response to gradually declining concentrations of ozone-depleting compounds in the atmosphere (Watson et al. 1992). Assuming continuing compliance with the amended Montreal Protocol targets, chlorine concentrations in the stratosphere should return to close to pre-1980 levels by the middle of the 21st century, allowing the ozone layer to repair itself.

The depletion of the ozone layer should reach its greatest extent in the coming decade. Low ozone values, comparable to those of the 1980s, will continue for at least another couple of decades beyond that. During that time, living organisms will continue to be at risk of exposure to higher intensities of UV-B.

Despite progress in controlling ozone-depleting substances — the London amendment requirements were met three years ahead of schedule — depletion of the ozone layer is not a fully resolved problem. At the moment, purely benign substitutes are unavailable for some CFCs. Consequently, these are being replaced by bridging chemicals that are less damaging to the environment but still not entirely harm-

Table 15.6

Phaseout schedule for ozone-depleting substances under the Montreal Protocol and its amendments and adjustments. and the corresponding Canadian targets

Ozone-depleting substance	Montreal Protocol	London amendments	Copenhagen amendments	Vienna adjustments	Canadian targets as of January 1, 1996
CFCs	50% reduction from 1986 levels by 1999	100% elimination by 2000	100% elimination by 1996		100% elimination by 1996
Halons	Freeze at 1986 levels by 1992	100% elimination by 2000	100% elimination by 1994		100% elimination by January 1, 1994
Carbon tetrachloride		100% elimination by 2000	100% elimination by 1996		100% elimination by January 1, 1995
Methyl chloroform		100% elimination by 2005	100% elimination by 1996		100% elimination by 1996
HCFCs		To be phased out between 2020 and 2040	Freeze consumption at base level[a] in 1996; 100% elimination by 2030	Phase out consumption in 2020; exemption of up to 0.5% of base year levels until 2030 for servicing existing equipment	Limit to uses where more acceptable alternatives do not exist beginning January 1, 1996; 100% elimination by 2020
HBFCs			100% elimination by 1996		100% elimination by 1996
Methyl bromide			Freeze production and consumption at 1991 levels in 1995	Reduce production and consumption by 25% by 2001; by 50% by 2005; and by 100% by 2010; with exemption for preshipment and quarantine applications	Freeze production and consumption at 1991 levels in 1995, and 25% reduction by January 1, 1998; 100% elimination by 2001 (except quarantine and preshipment applications in both cases)

Note: The 100% elimination targets are subject to the Essential Use Provision, which may allow for continued use if it is essential for the health, safety, or functioning of society and if there are no technically and economically feasible alternatives or substitutes available

[a] Base level is defined as the 1989 consumption of HCFCs plus 2.8% of 1989 consumption of CFCs.

Source: UNEP (1993); Environment Canada (1994); Ozone Protection Programs Section, Commercial Chemicals Evaluation Branch, Environment Canada

less. The most common of these replacements has been a related group of compounds known as HCFCs. Because HCFCs have a much shorter atmospheric lifetime than CFCs — anywhere from 1 to 20 years — they are less likely to be carried into the stratosphere. As a result, their potential for destroying ozone is, in most cases, only about 2–5% that of CFCs.

HCFCs are also greenhouse gases, as are hydrofluorocarbons (HFCs), another common group of CFC substitutes. Although most of these are less powerful greenhouse gases than any of the CFCs, they are all much more powerful than carbon dioxide, the most common anthropogenic greenhouse gas. With greater quantities of these CFC substitutes coming into use, their presence in the atmosphere is increasing rapidly. Concentrations of HCFC-22, the most common HCFC, are growing at a rate of 7–9% a year, whereas concentrations of some other CFC substitutes are growing at even faster rates (Midgley and Fisher 1993).

Under the Copenhagen amendment, consumption of HCFCs was to be frozen at 1989 levels at the beginning of 1996, phased down to 10% of 1989 levels by 2014, and eliminated entirely by 2030. Because HFCs are not ozone-depleting substances, they are not covered under the Montreal Protocol. However, many countries, including Canada, are considering taking measures to limit their HFC emissions.

Although the production and consumption of CFCs are slated for virtual elimination by 1996, large quantities of these compounds will remain in use after that date. A large proportion of these are in air conditioners and refrigeration units built before the introduction of alternative refrigerants, and many of these units may remain in service for a further decade or more. A smaller quantity of CFCs will remain in use in certain medical and laboratory applications. These applications, designated as essential uses under the Copenhagen amendment, will be supplied from current stockpiles by recycling CFCs now in use or by using new CFCs produced in countries that have been given permission to do so. Although surplus stocks of CFCs may eventually be destroyed, appreciable quantities will remain for some time and will continue to be a potential threat to the ozone layer.

Expectations for the recovery of the ozone layer could also be delayed by other ozone-depleting forces that are not yet completely understood. More needs to be known, for example, about the role of hydrogen oxides (i.e., water, hydrogen peroxide, and the hydroxyl and hydroperoxyl radicals) and nitrogen oxides in stratospheric ozone depletion, especially if supersonic commercial airliners come into common use in the 21st century. An important current objective of the Canadian stratospheric ozone science program is to better determine the mechanisms responsible for ozone depletion at mid-latitudes (e.g., over Canada), where about half the depletion that has actually occurred can be explained. Understanding of the major ozone-depleting processes is still progressing. Accurate predictions of future ozone levels await this understanding.

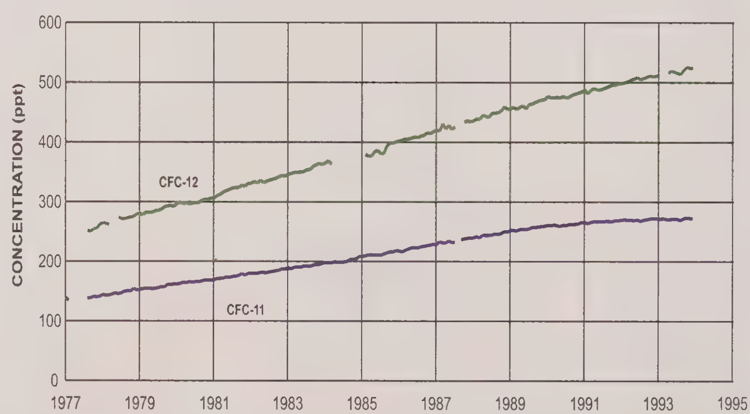
CONCLUSION

Stratospheric ozone depletion and an enhanced greenhouse effect both have the potential to jeopardize Earth's life support system. The move to control ozone-destroying substances represents a major success story in international cooperation. Scientific inquiry led to a high level of certainty surrounding the issue and the implementation of sound environmental policies worldwide. The threat was real and imminent; the culprits were recognizable and controllable.

Actions for controlling greenhouse gas emissions are much less advanced than those for ozone depletion. That is partly because of the greater level of scientific uncertainty surrounding the warming issue. Global warming does not have its equivalent of the "ozone hole" to demonstrate the problem. However, recent modelling results (Kerr 1995), which include the effects of increasing concentrations of both greenhouse gases and aerosols, indicate that human-induced warming of the planet may now be under way.

Figure 15.13

Average global atmospheric concentrations of CFC-11 and CFC-12



Note: Line breaks represent missing data; global monthly means are based on measurements from seven stations worldwide.

Source: Climate Monitoring and Diagnostics Laboratory, National Oceanic and Atmospheric Administration, Boulder, Colorado.

Controlling and reducing greenhouse gas emissions are more formidable social and economic challenges than eliminating ozone-depleting substances. The elimination of CFCs and other ozone-depleting substances affects a small part of the global economy, and practical alternatives have been available in most cases to ease the transition. However, greenhouse gases come largely from fossil fuels, and energy from fossil fuels is the basis of our industrial economy. Reducing greenhouse gas emissions to the level necessary to stabilize their atmospheric concentrations will require a massive reorientation of the world's energy use away from carbon-based fuels and towards more benign alternatives and greater energy efficiency. Without adequate progress in this direction, it might also require a considerable reduction in overall energy consumption. These adjustments could have enormous social, economic, and political costs if they are undertaken too quickly, especially as many alternatives to fossil fuels are not yet economically practical for use on a large scale.

In the final analysis, some benefits might accrue regionally and sectorally from a *slightly* warmer climate. However, the risk of aggregate net damage would increase as climate change intensified and disruptions to "normal" existence became more pronounced. The precautionary principle that underlies the National Action Program on Climate Change supports the adoption of greenhouse gas mitigation measures that go beyond "no regrets" options (the latter being those measures that are justified for reasons other than combatting climate change). Without decisive action, greenhouse gas concentrations may rise to levels that present grave consequences for both the natural world and human civilization. That is why it is so important for the public and policymakers to respond to climate change now.

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PART V

TOWARDS ENVIRONMENTAL SUSTAINABILITY

Chapter 16 Progress Towards Environmental Sustainability

Highlights

Canada has made measurable progress towards environmental sustainability in some important areas, but difficult challenges lie ahead. Overall, many of the most visible and dangerous stresses on the life support system have been reduced, but a number of environmental stresses continue unabated both in Canada and in other parts of the world, and new areas of environmental concern are emerging.

■

Thus far, Canada has achieved its international objectives for phasing out ozone-depleting chemicals and reducing sulphur dioxide emissions, met its interim national targets for reductions in packaging and solid waste, and made progress in creating new protected areas. Still, the challenge remains to reach the more stringent long-term targets necessary to achieve sustainability in these areas and to develop and meet sustainability objectives for other environmental components, resource sectors, and ecosystems.

■

In the face of specific goals, new regulations, depleted resources, and public pressure, industry has taken the lead in reducing pollution and promoting resource conservation. Strong management response has been shown by such industries as pulp and paper (elimination of dioxins and furans), manufacturing (reduction of packaging), agriculture (conservation tillage), forestry (reforestation), and chemicals (Responsible Care® program). Given clear choices, Canadians as individuals, groups, or managers of institutions have often taken significant strides towards sustainability, in many cases achieving environmental and economic goals in tandem.

■

Where there has been a concerted effort towards environmental sustainability, positive results have been achieved. There have been notable successes in cleaning up some of the most contaminated sites through remedial action plans. Many parts of the Great Lakes, the St. Lawrence River, and the Fraser River are, for example, much cleaner than they were five years ago. However, where problems are widespread, sources diffuse, and responsibilities dispersed, less progress has been made in addressing issues, such as urbanization of prime farmland, leaking underground storage tanks, and groundwater contamination.

■

Although Canada's environmental record is among the best in the world, Canadians still face significant environmental problems. Some of these are associated with past environmental debts; others are connected with emerging evidence of new areas of concern and with changing institutions. Environmental debts have accrued in the form of contaminated sites, polluted ecosystems, depleted fish stocks, and residual contaminants in soils. New concerns regularly arrive, such as fine particulates in urban air, new toxic substances, and unwelcome surprises relating to the spread of contaminants throughout the world. The size of the task is magnified by the reassessment and reduction of basic institutions and traditional sources of funding and leadership by government at all levels.

■

There is a move towards broader consultative approaches to resource management. Inclusion of environmental values into corporate and government decision-making is increasingly evident, although there is still much to be done to make decision-making more "green." At the same time, the sunsetting of programs in all jurisdictions is reducing Canada's ability to monitor environmental trends and its capacity to research the causes and effects of environmental problems.

■

There is a heightened awareness of environmental issues among Canadians, and environmental preservation has become a core value to most citizens. The general public has shown a willingness to undertake activities that benefit the environment (such as recycling, composting, and tree planting) where it is straightforward to do so. Moreover, where economic instruments are applied in conjunction with education (e.g., water pricing by volume and increased energy prices in the late 1970s), positive changes in consumption patterns have been quick to follow.

■

However, there has been no substantial change in Canadians' high consumption levels. Canadians remain among the highest per capita users of energy and natural resources and among the highest per capita producers of household waste. Fundamental changes to those features of Canadian lifestyles that add to environmental stress have not occurred. High energy use (stemming in part from a preference for single detached homes), high levels of auto ownership and use, and sprawling cities continue to be the norm, despite some policies and programs that have attempted to change this direction.

■

Canada is one of the cleanest nations on Earth, but serious environmental problems remain that threaten its sustainability. Achieving the sustainability goals of the World Conservation Strategy, the Brundtland Commission, and *Agenda 21* will involve hard choices and fundamental changes in behaviour for both governments and individuals. Can Canadians and their governments find the formula that will yield continued economic well-being while maintaining the integrity of the ecological system that supports the economy? Can we develop production systems, industrial codes of practice, fuel efficiency standards, and building codes, for example, that are more efficient and do not undermine ecological integrity? Can governments further develop frameworks and regulations that provide a basis for sustainability through their influence on millions of individual decisions about such small but ecologically crucial choices as where to live and how to travel to work? A sustainable path is in view, but Canadians, individually and collectively, have still to come to terms with these fundamental issues.

■

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Introduction

What do Canadians know about the changes taking place in their environment? What are the impacts of their actions? Is there cause for concern, or is there reason to rejoice? Is Canada now on a path that will sustain those values most important to its citizens?

The simple answer to these questions is that Canada has made measurable progress towards sustainability in some important areas, but difficult challenges lie ahead. Areas of improvement include the phaseout of ozone-depleting chemicals, continuing declines in sulphur dioxide emissions, reductions in the volume of solid waste and packaging, and increases in the number of protected areas. Trends towards the use of sustainable agricultural practices, the successful regeneration of forests, and reclamation of mining sites are positive signs. However, fundamental changes to those features of Canadian lifestyles that add to environmental stress have not occurred. High energy use (stemming in part from a preference for single detached homes), high levels of auto ownership and use, and sprawling cities continue to be the norm, despite some policies and programs that have attempted to change this direction. A large legacy of unresolved environmental debts has accumulated in the form of polluted ecosystems, contaminated sites, depleted fish stocks, and the presence of residual contaminants in soils. Overall, many of the most visible and dangerous stresses on life support systems have been reduced, but many other environmental stresses continue unabated both in Canada and in other parts of the world, and new areas of environmental concern are emerging.

With better understanding of the complexity of the ecosphere and the effects of human activity on it, scientists and decision-makers have increasingly debated the nuances of sustainability: what is it, precisely, that Canadians need or want to sustain? Obviously, they seek to sustain both human well-being and environmental quality. Indeed, Canadians, along with the global community, have come to learn that environmental, economic, and social values are inseparable and that healthy societies and productive economies are contingent upon a healthy environment. A related question asks how much of our present well-being is purchased at the expense of environmental quality and of the ability of the natural resource base to continue to support future needs. How can we define the trade-offs between current demands on the environment and other critical values and devise ways to satisfy current needs without sacrificing the ability to serve long-term needs?

Sustainable development

The concept of sustainability is not new. Indeed, it is a common theme in the oral histories of tribal peoples in all parts of the world and is often presented as a parable of the importance of living within and as part of nature, of saving for the future and ensuring that the environmental attributes that support life are maintained. In its modern incarnation, the idea of sustainability underlies the conservation movement of the last century and, more recently, the development of the World Conservation Strategy and the work of the World Commission on Environment and Development (the Brundtland Commission) and the United Nations Conference on Environment and Development (UNCED). The common interpretation of the concept of *sustainable development* is that development should meet the needs of the present without compromising the ability of future generations to fulfil their own needs (World Commission on Environment and Development 1987). An interesting parallel to this idea can be seen in the tradition of some of Canada's First Nations, of "planning for seven generations." In discussing important decisions, this tradition was accomplished by designating one person to represent the interests of the seventh generation to come (Nickerson 1990).

During the past decade, the concept of sustainable development has been closely scrutinized. Many people have questioned whether development (if defined in terms of economic growth) can be sustained indefinitely. Others have used sustainable development as a slogan to advance their own agendas, placing the emphasis on the half of the term that serves them best. Although the term has been abused and misused, it has also created a common point of discussion among disparate interests where none existed before. Its very ambiguity has encouraged a diverse assortment of groups to discuss and define the range of environmental functions and the values they wished to support.

The 1992 Earth Summit (UNCED) in Rio de Janeiro was, to a great extent, a product of this debate. For months leading up to and following the two-week conference, the attention of the world focused on the interfaces between the environment, the economy, society, and health. The results of UNCED included *Agenda 21* (a blueprint of actions to support sustainable development into the next century), the Rio Declaration on Environment and Development, the Framework Convention on Biological Diversity, the Framework Convention on Climate Change, and principles for the sustainable management of forests. Canada is a signatory to each document and has ratified both conventions.

Understanding change

In the past decade, Canadians have become more aware of the effects that human activities are having on ecosystems from the local to the global level. At the same time, they have also become more aware of the limited capacity of ecosystems to absorb these changes. With expanding population and greater consumption and despoliation of life-sustaining resources, the human ecological footprint is becoming larger. As *The state of Canada's environment — 1991* noted, there is less and less natural environment available for each resident of the globe (Government of Canada 1991). This trend has continued over the last five years. As of 1996, there are over 400 million more of us, and there are 19 million fewer hectares of arable land globally. In 1991, the International Development Research Centre (IDRC) estimated that there were 2.42 ha of arable land available to each person on

the planet. In 1996, there were 2.23 ha available per person.[1] The 1991 report also noted that persistent toxic substances, transported by wind, water, and the food chain, could be found in even the most remote communities of Canada's North. It has become apparent that there is no place on Earth that has not yet been infiltrated by these substances. Moreover, the effects of many of these may not become evident until years or perhaps even generations after their release (see Chapter 10).

Environmental impacts may be more than the result of simple cause-and-effect relationships. Synergistic effects, arising from the interaction of multiple contaminants or stresses, are also important. Scientists may, for example, know the effect when one household cleaner is dumped into a stream, but few know precisely what the result will be if the cleaner mixes with post-rain pesticide runoff from farms and the waste of the chromium plating plant upstream. Yet human and wildlife populations downstream must use the cumulative result of these wastes for habitat, drinking water, or irrigation.

Some environmental change happens very slowly. Climate change, detoxification of watercourses, and the recovery of land from salinization can take decades. As a consequence, this report is able to identify very little change from the last state of the environment report in some areas, although efforts have been made to reduce pollutant loadings or to reestablish fish stocks, for example. In other areas, five years have brought about real progress, as the results of concentrated efforts to reduce the use of ozone-depleting substances and emissions of sulphur dioxide, for example, attest.

1. These figures were calculated by taking the Food and Agriculture Organization of the United Nations' 1991 estimate of 13 042 million hectares, subtracting 1 ha every 8.23 seconds (the IDRC's estimated loss of arable land worldwide), and dividing by the estimated midyear world populations in 1991 and 1996.

A framework for assessing progress towards sustainability

Are we there yet? This chapter assesses Canada's progress and compares it with world trends and with the environmental goals to which the Government of Canada, the provinces and territories, businesses, and communities have committed themselves.

State of the environment analyses typically pose five key questions: What is happening? Why is it happening? Why is it significant? What is being done about it? Is it sustainable? All of these are considered, either directly or indirectly, in the following sections. In doing so, this chapter highlights some significant new initiatives as well as important changes in society that may favour or obstruct Canada's path towards sustainability. In addition, new environmental concerns, revealed by improved monitoring and continuing research, are identified. As in the 1991 report, what Canadians need to know, but do not, is also outlined. In particular, the chapter identifies areas of concern for which there is either no information or too little and attempts to determine whether Canada's institutions are moving to fill the gaps.

Sustainable development seeks to balance a number of apparently competing environmental, economic, and social goals. Thus, individuals, communities, and nations often arrive at decision points where trade-offs and choices between environmental and other goals seem necessary. The most desirable outcomes for such decisions are win–win solutions that accomplish both environmental and economic goals. Achieving such perfect outcomes is often difficult, however. Although such baseline values as equity (within and between generations), respect for biodiversity, protection of human health, and provision of adequate food and lodging are all important, the task of integrating these values effectively into the decision-making process along with more specific environmental and economic goals is still a challenge.

The framework of the revised World Conservation Strategy has been adopted for the assessment of Canada's progress towards sustainability. The World Conservation Strategy has three core goals:

- maintaining essential ecological processes and life support systems;
- preserving biological and genetic diversity; and
- ensuring the sustainable use of species and ecosystems.

To these, a fourth has been added: improving human health and the quality of life

Box 16.1
An international framework for integrating development and conservation

The World Conservation Union (IUCN), the United Nations Environment Programme (UNEP), and the World Wide Fund for Nature (WWF) have formulated the following goals for national governments, to be implemented by the year 2000:

- *completion of systems of national environmental law, backed by effective enforcement machinery, in all countries;*
- *completion of reviews of economic and administrative policy in all upper-income countries, with adjustments to these policies where necessary;*
- *creation of an integrated global system, including the Environmental Early Warning Mechanism, to monitor a set of agreed indicators of human development, human freedom, environmental quality, and ecological sustainability;*
- *establishment of a system of sustainability reporting in all countries; and*
- *adoption by all countries of a national strategy for sustainability, guided by information on the quality of human life and the environment and having the enhancement of both as its chief goal.*

Source: IUCN et al. (1991).

(Box 16.1). The first three goals were the foundation of the 1980 World Conservation Strategy (IUCN[2] et al. 1980). The fourth has been added to give better representation to human systems, as stressed by the Brundtland Commission (World Commission on Environment and Development 1987; see IUCN et al. 1991 for a discussion of World Conservation Strategy goals).

The World Conservation Strategy goals have been adopted as the framework for reporting because they provide a well-accepted set of objectives that succinctly address all the major core values associated with ecological sustainability. They offer an organized framework for the assessment of anthropogenic stresses and serve as a short but comprehensive checklist against which progress towards or away from sustainability can be assessed. The World Conservation Strategy goals encompass the fundamental building blocks for ecological security, economic activity, and social stability. If these are compromised, the ability to continue to serve human wants and needs (for goods, services, and experiences) as well as the needs of other species is also compromised. Although the World Conservation Strategy framework differs somewhat from the more sectoral and issue-oriented approach taken by the Brundtland Commission and more recently in *Agenda 21*, it is nevertheless a useful way of organizing the analysis of the main environmental stresses, conditions, and responses that are of concern. The use of this framework will facilitate comparison with the conclusions of the 1991 report, which also used World Conservation Strategy criteria.

The World Conservation Strategy goals are reflected as well in the Government of Canada's *Guide to green government* (Government of Canada 1995a), which provides a starting point for departments to prepare sustainable development strategies with respect to sustainable natural resource use, human and ecosystem health, international commitments, equity, and quality of life and well-being.

2. IUCN stands for the World Conservation Union, formerly the International Union for the Conservation of Nature and Natural Resources.

Are the Condition and Use of the Environment in Canada Becoming More Sustainable?

This section summarizes changes in the condition of the Canadian environment and the stresses on it and identifies areas of concern that have emerged since the 1991 report. Following the World Conservation Strategy framework, it focuses on threats to essential ecological processes and life support systems, the impacts of human activities on biological diversity, trends in the sustainable use of ecological resources, and risks to human health and quality of life. Specific reference is made to other chapters in the 1996 *State of Canada's environment* report.

Essential ecological processes and life support systems

Ecosystems provide the essentials of life, such as air, water, nutrients, energy, and habitat. They also provide a framework within which the supply and quality of these essentials are sustained by such processes as the water and carbon cycles, soil production, toxic buffering, and waste assimilation. Because of its particular mix of physical, chemical, and biological characteristics, each ecosystem is unique. In turn, all organisms, including humans, depend on the specific attributes of the ecosystem of which they are a part. Alterations to any of these attributes or to the linkages between one ecosystem and others can therefore change the ability of any part of the planet to act as a life support system or as a resource base for human activity.

During the past five years, there has been continuing evidence of the impact of human activities on ecosystems at all scales. These impacts have ranged from global effects on the atmosphere to local contamination of watercourses and soils. Expanding populations and growing economies tend to increase the consumption of resources and intensify the human impact on the environment. New technologies, such as those that introduce or increase the level of potentially toxic substances in the environment, may also have harmful effects. On the other hand, technological advances that benefit the environment (e.g., advances in alternative energy technologies such as solar and wind power) in combination with more comprehensive regulatory initiatives and voluntary measures have helped to make some Canadian practices more supportive of sustainable development.

Changes to the atmosphere

Canada has led the worldwide endeavour to eliminate chlorofluorocarbons (CFCs). The 1991 *State of Canada's environment* report identified Canada's global leadership in the effort to eliminate the use of CFCs and halt global stratospheric ozone depletion. Most of the world's nations have now agreed to the 1987 Montreal Protocol, which is aimed at eliminating the production and use of CFCs and other ozone-depleting chemicals. Many, including Canada, have also agreed to subsequent amendments to accelerate and expand the provisions of the original agreement. Canada has been successful in meeting its obligations under these agreements. It virtually eliminated the use of new CFCs by the target date of December 31, 1995, although a large volume of old CFCs remains inside refrigerators and air conditioning systems currently in use.

Nevertheless, stratospheric ozone depletion remains a serious problem. The present substitutes for CFCs are primarily hydrochlorofluorocarbons (HCFCs). Although considered to have significantly less ozone-depleting potential, HCFCs are growing in use, and the resulting increase in releases of these substances will continue to contribute to depletion of the ozone layer. Canada, with other countries, is now placing limits on HCFC consumption, with the intention of freezing use at 1989 levels beginning in 1996. In addition, Canada will eliminate their use entirely by 2030. There are also continuing efforts to limit the production and use of other ozone-depleting substances such as methyl bromide, for which there has been a successful voluntary program to establish tradable market permits to control consumption.

Severe stratospheric ozone depletion is currently limited to the Antarctic and, to a lesser extent, the Arctic. Depletion over the mid-latitudes has been less severe — about 7% in the northern hemisphere since 1978 — but it has nevertheless allowed an increase in ultraviolet-B (UV-B) radiation at the Earth's surface, and this may already be leading to changes in aquatic food chains in Canada (see Chapter 10, "Fresh water" component). Human populations may also be more vulnerable, as overexposure to UV-B radiation is known to increase the incidence of skin cancer, cataracts, and immunodeficiency (see Chapter 15). The ozone layer will likely take 50 years or more to restore itself fully once ozone-depleting substances are phased out globally.

Scientists agree that the rate and pattern of climate change over the past century, taken together, point towards a discernible human influence on the world's climate. Global progress towards stabilization of greenhouse gas emissions has been slow, however, hampered by uncertainties about the magnitude and timing of climate change and by the reluctance of many sectors of the economy and of the general public to accept the reality of human-induced climate change and to incur costly investments in alternative technologies and changes in lifestyles. The weight of scientific evidence supports the conclusion that, unless actions are taken soon to limit emissions, the mean planetary temperature could rise by 0.1–0.5°C per decade over the next century, producing what may be the highest global temperatures of any time in the past 100 000 years.[3] As a result, sea levels would rise, and entire regions would experience major ecological changes. Improved global climate models will help to refine these predictions and improve scientific understanding of the relationships among elements of the climate system and their links to human actions.

Canada's emissions of carbon dioxide (CO_2) were 469 million tonnes in 1993, about 2% of the world's total and fifth highest of the Organisation for Economic Co-operation and Development (OECD) member countries (OECD 1995; A. Jaques, Pollution Data Analysis Division, Environment Canada, personal communication). Canadian emissions are still comparatively small, however, in relation to those of our American neighbours. Both global and Canadian emissions grew by 12% between 1982 and 1991.

As a signatory to the Framework Convention on Climate Change, Canada is committed to take steps to reduce its emissions of greenhouse gases. In common with other industrialized countries, it has set itself a target to aim at stabilizing greenhouse gas emissions at 1990 levels by the year 2000. Achieving this target will not be easy. Without significant action by Canadian industries under the Voluntary Challenge and Registry Program and additional government measures under Canada's National Action Program on Climate Change, energy-related carbon dioxide emissions will likely increase by 13% over 1990 levels by the year 2000, as a result of normal population and economic growth alone (Canadian Council of Ministers of the Environment 1995). (Details on Canadian programs are provided below in "Progress towards sustainability" and in Chapter 15.) At the global level, the prospects of progress are not encouraging, as many nations anticipate an increase in their use of fossil fuels. The growth in fossil fuel use is expected to be particularly large in many developing countries.

Acidic deposition, a result of the long-range transport of air pollutants such as sulphur dioxide and oxides of nitrogen (NOx), has been a focus of pollution control activity in Canada and the United States for more than a decade. Some positive results are now evident. From 1979 to 1993, the average amount of sulphur dioxide in the air in Canada fell by half. Canada also has met its emission reduction targets under the Canada–U.S. Air Quality Agreement, with a 56% decrease in eastern Canadian sulphur dioxide emissions, from 3.8 million tonnes in 1980 to 1.7 million tonnes in 1994. In addition, a key indicator, the area of heaviest wet sulphate deposition (in excess of 20 kg/ha per year), decreased by 59% in eastern Canada between 1980 and 1993. Still, there remains a legacy of past contamination: Canada has at least 150 000 lakes that are acid-damaged, of which about 14 000 are considered to be severely affected, and acidity continues to affect many soils and crops.

Between 1979 and 1993, average nitrogen dioxide concentrations at urban measuring sites fell by 28%, largely because of reduced emissions from some industrial sources and cleaner-running cars. However, over the same period, the number of motor vehicles on the road increased, with the result that total emissions remained relatively unchanged. Canadian sources now emit 2.0 million tonnes of nitrogen oxides per year, the fifth highest amount of the OECD countries (OECD 1995). Motor vehicles remain the principal source of nitrogen oxides and volatile organic compounds (VOCs) in Canada's air and also produce 27–32% of the nation's carbon dioxide emissions (see Chapter 11).

The last 15 years have seen significant gains in urban air quality in many centres, and in most Canadian cities the maximum acceptable levels of the National Ambient Air Quality Objectives are now exceeded only infrequently. Average levels of pollutants declined greatly between 1979 and 1993: carbon monoxide dropped by 56%, sulphur dioxide by 46%, and airborne particles by 38%. The virtual elimination of lead from automobile fuels has led to a dramatic 95% decrease in airborne lead concentrations since 1979. This reduction was reported in the last *State of Canada's environment* report and has remained in place. These gains have come from the control of pollution at source through regulation and voluntary reduction of industrial emissions, changes in automobile exhaust standards, and limitations on open burning. At the same time, however, some major air quality concerns remain, particularly in cities and in areas downwind of major Canadian and U.S. pollution sources.

Concern is growing, for example, over levels of fine particulate matter (less than 10 µm in diameter) and very fine particulate

3. This projection is based on the assumption that greenhouse gas emissions will double over the next century (see Chapter 15).

matter (less than 2.5 μm). These particles, which are inhalable and not easily filtered, may contribute directly to respiratory diseases by conveying toxic substances into the lungs. Another emerging concern is benzene, a toxic substance released in gasoline vapour and vehicle exhaust. Benzene levels in urban air have been monitored regularly only since 1989 (see Chapter 12).

Ground-level ozone, the product of interactions involving nitrogen oxides and VOCs in the presence of sunlight, is now considered Canada's most serious local air pollution problem. Even in areas some distance from sources, ozone concentrations can be high. The southern Maritimes, for example, commonly record some of the highest ozone levels in Canada, the result of pollutants originating in the New England states and brought in on southwest winds. Episodes of ozone pollution in Nova Scotia and New Brunswick typically peak in the middle of the night, about 12 hours after the evening rush hour in Boston. Other areas in which ground-level ozone is a major problem are the Windsor–Quebec City corridor in Ontario and Quebec and the lower Fraser Valley in British Columbia.

So far there has been little progress in controlling ground-level ozone, although some progress has been reported in British Columbia as a result of the regulation of vehicle emissions. Emissions of the principal ozone precursors — VOCs and nitrogen oxides — have remained fairly constant for a decade or more (for VOCs, approximately 2.0–2.8 million tonnes per year since 1985; for nitrogen oxides, a relatively steady 2.0 million tonnes per year since 1980), despite substantial reductions in per-unit vehicle emissions. Along with other toxic chemicals and small particulates, ozone and its precursors may be contributing to a variety of health effects in humans, including, for example, an increasing incidence of asthma (see Chapter 10).

Alteration of ecosystems

Globally, alteration of ecosystems remains one of the most serious of all environmental concerns, as desertification, loss of tropical rain forest, and wetland conversion continue on a large scale. As Table 16.1 indicates, Canada, too, continues to alter natural cover and place further stresses on its natural systems, mainly through the effects of continued economic and population growth. The Great Lakes–St. Lawrence basin as well as the Atlantic Maritime and Prairies ecozones have already been substantially altered by humans, reflecting the past and current role that these ecozones have played in the production of goods and services for Canadians. Parts of other ecozones (e.g., the lower Fraser and Okanagan valleys of British Columbia, the Nickel Belt in the Boreal Shield ecozone, and the areas surrounding most urban centres) are essentially human-dominated systems. In some places, essential ecosystem functions, such as chemical detoxification in wetlands, have been lost. In others, biological production has been reduced or destroyed, as in the case of some major commercial fish stocks. The management of these ecosystems to serve the wants and needs of Canadians has altered their original ecological capacity, and management decisions continue to affect the biological diversity and physical characteristics of these regions.

Through the long-range transport of atmospheric pollutants, northern ecozones are also exposed to the effects of industrial and agricultural activities in other parts of the globe as well as to the smaller-scale effects of human activities within the region itself. Still, despite inputs from places far away, stresses on many of the more northerly ecozones remain relatively small, particularly with the slowing of economic activity in resource industries in the early 1990s and fewer new megaprojects. In the Arctic and Taiga ecozones, a reduction in the development of reservoirs, dams, and pipelines has reduced the overall level of ecological stress. Similarly, recent stresses have remained relatively small in the Atlantic Maritime and Boreal Shield ecozones as a result of an economic downturn and changes in the planning and management of forestry operations, pulp and paper production, and some aspects of mining.

In southern Canada, the expansion of urban centres onto good farmland and vulnerable ecosystems has continued, even though most jurisdictions have introduced environmental review procedures for development over the past two decades. An important aspect of the problem is that Canada's major urban centres tend to be located amidst the most productive farmlands. In fact, the initial success of many of these centres was based on the productive agricultural use of the surrounding lands. The pressure of urban expansion has been especially intense in the Great Lakes–St. Lawrence basin, one of the smallest geographic regions in Canada, but home to 51% of the nation's population and more than half of its industrial infrastructure. Vancouver, in the Pacific Maritime ecozone, faces a particularly acute dilemma. Either it must adopt a more compact form of development or it must expand onto the limited valley bottom lands that are the region's agricultural base. Between 1966 and 1986, over 60% of Canada's urban growth was on prime agricultural land. The broader effects of urban-related activity also caused changes in the usage patterns of much larger areas around these cities. One consequence has been the rapid growth of small towns and villages and the building of rural residences within commuting distance of the larger centres. Although satellite imagery shows that this trend is continuing, specific data on changes in rural–urban land use have not been fully developed since 1986.

In the Prairies ecozone and the Great Lakes–St. Lawrence basin, most of the lands are intensively used. The bulk of each region is privately owned and operated as farms or woodlots; built up as cities, towns, and villages; or used to provide facilities, such as roads and railways, pits and quarries, and landfills, that support human activity. The pace of growth of cities and industries has diminished somewhat since the last decade because of a slowdown in overall economic activity. Still, as shown in the lifestyles chapter (Chapter 2), consumption of most goods and services has continued to climb. This has increased demands for space for both production and waste disposal, although

Table 16.1
Are environmental conditions in Canada becoming more sustainable?

Ecozone/ecozone grouping	Selected trends grouped by World Conservation Strategy goals: Maintain life support systems	Preserve biodiversity	Sustainable use of species and ecosystems	Improve human health and quality of life
Pacific and Western Mountains 3 287 000 people[a] GDP $73 140 million	• Lower Mainland experiences high levels of ground-level ozone • DDT and PCBs found in remote areas owing to LRTAP • Clayoquot Sound agreement on management of old-growth forest • Closure of shellfish beds because of contamination from sewage and other causes (120 000 ha) by 1995 • Declining levels of dioxins and furans permitted 48 465 ha of shellfish beds to reopen (1995)	• 800 protected areas with 14 million hectares (10% of ecozone grouping), an increase since 1991 • Coastal rain forests a major concern; 2.2 million hectares logged in past 120 years (of 10 million hectares) • Interior grasslands and wetlands under continuing development pressure • Only 0.5 million hectares of marine ecozone protected (of 30 million hectares) • 65 endangered and 24 extirpated species in ecozone grouping	• B.C. Forest Practices Code (1993) sets guidelines for sustainable forest management • Forest Renewal B.C. created to ensure productive capacity of forests; extent of clear-cut forest harvesting reduced • Some salmon populations declined (i.e., Chinook, Coho, and also Sockeye salmon in Fraser River) • Pacific Herring well managed; most other fish stocks in good condition • Organochlorines from B.C. pulp mills declined 56% (1991–1994)	• Rapid urban growth: interior valleys and Lower Mainland under development pressure • Water supply systems to be upgraded to meet population demand • Sewage treatment systems need upgrading in a number of centres
Central Plains 3 851 000 people GDP $90 760 million	• Conservation practices have moderated deterioration of agricultural soils • Eutrophication is the most important water quality issue • Shortages, salinization, and pesticide contamination are other water concerns	• 3% of Prairies ecozone protected; a significant increase, 1984–1994 • 19 species at risk, an increase of 7 since 1990 in Prairies ecozone • Habitat loss continues for some species • NAWMP preserved 320 000 ha of wetlands, 1985–1995, and duck populations recovering from historic lows in early 1980s	• Conservation tillage is increasing; summerfallowing declined 27%, 1971–1991 • Greater crop diversity; less monoculture • 0.5 million hectares of marginal land converted to permanent cover (reducing erosion potential) • Area of fertilizer use levelled off; area of pesticide application declined 1986–1991 • Climate change could have major implications for ecosystem and resources	• Rural depopulation is continuing • Drinking water quality remains a concern • Municipal contribution to water pollution is declining
Boreal Shield 3 540 000 people GDP $62 750 million	• Many shield lakes and shallow soils are extremely sensitive to acidic precipitation • Acidic precipitation may have weakened vigour and growth rate of forests in sensitive areas • Adverse impacts of mining lessened in past decade owing to pollution control technologies and more comprehensive mine decommissioning • Many orphaned mine sites	• 16 species at risk in ecozone • Three new provincial parks proposed, and one major provincial park expansion • Recent changes in forest management: major decline in pesticide use; decreased release of toxins from pulp mills; more ecosystem-based forest inventories; and integrated forest management plans	• Ecozone has 39% of Canada's hydroelectric capacity; long-term maintenance and reclamation of aging dams are emerging environmental concerns • Ecozone contains nearly one-half of Canada's timber-productive forestland; annual harvest doubled to 425 000 ha (1920–1992), peaking at 543 000 ha in 1987 • Clear-cutting is the predominant method of forest harvesting; average size of clear-cut blocks reduced	• Mining is the mainstay of 80 communities; forestry is the primary economic activity in many of the rest • Tourism, particularly nature-oriented, is an emerging activity • Much of the ecozone is under Native land claims

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Table 16.1 (continued)
Are environmental conditions in Canada becoming more sustainable?

Ecozone/ecozone grouping	Selected trends grouped by World Conservation Strategy goals			
	Maintain life support systems	**Preserve biodiversity**	**Sustainable use of species and ecosystems**	**Improve human health and quality of life**
Great Lakes–St. Lawrence basin 14 016 000 people[b] GDP $325 200 million	• Phosphorus inputs to Great Lakes reduced as per Great Lakes Water Quality Agreement, and eutrophication disappeared from open water • Direct emissions of persistent toxic substances to receiving waters reduced, but level of some toxic chemicals in fish and birds about the same since 1985 • Atmospheric deposition of toxics a major input into the lakes • Climate change projected to lower lake water levels, decrease groundwater, increase drought, change habitat, and increase smog	• Since 1810, 139 aquatic species introduced to Great Lakes, largely by vessels on St. Lawrence Seaway • Resurgence of fish species (Lake Trout, Lake Whitefish, Lake Herring) caused by nutrient controls, catch limitations, and Sea Lamprey control • 27 endangered and 32 threatened species (1995) • Urbanization, agricultural development, and introduced species have reduced biodiversity • Original Carolinian forest ecosystem extensively changed; only 3–16% fragmented forest cover • St. Lawrence Beluga population increased an estimated 3–4% per year (1976–1995)	• Intensive agricultural production linked to soil erosion, eutrophication of surface water, and contamination of rural well water • Pesticide contamination declined substantially • Over 50% of farms practise crop rotation or apply winter cover crops; 20% undertake conservation tillage or zero tillage • Urbanization of prime agricultural land continues	• Highest levels of ground-level ozone in Canada; strongly linked to increases in respiratory illness • PCBs and DDT in human breast milk decreased considerably since the early 1980s • Degraded rivers (e.g., Rouge, Don, and Humber in Toronto) are being rehabilitated, largely by local citizens' efforts
Atlantic 2 510 000 people GDP $39 920 million	• Municipal sewer discharges cause 20% of shellfish bed closures • Acid-generating emissions reduced, but lakes not recovering as expected; 30% of lakes acidified • Ground-level ozone causes air quality problems in Bay of Fundy area	• Forests cover 90% of ecozone; most areas logged several times • Few pockets of true old-growth hardwood forest remain • 65% of original coastal marshes drained and diked, mostly for agriculture, causing reduced wildlife populations • 385 protected areas: 8.4% of terrestrial ecozone • Five wetlands designated by Ramsar Convention, including the Bay of Fundy shorebird reserve	• Cod and other Atlantic groundfish stocks in serious decline; fishing moratorium on these species • Landings of pelagic and invertebrate species generally stable, 1985–1995 • Aquaculture growing • Two working-scale model forests in ecozone • Soil erosion on cultivated land is serious; water erosion on potato lands costs $15 million per year in N.B. and P.E.I.	• 1.2 million people rely on groundwater for domestic needs; contamination can be a problem • Sydney Tar Ponds cleanup not successful; work continues • Sewage treatment program in Halifax has not proceeded • Fishing fleets and fish processing are declining in some areas, and regional economy is changing
Taiga 65 000 people GDP $1 790 million	• High potential impact from climate change; up to 10°C difference in winter: may benefit forests, but may cause permafrost degradation	• Taiga ecosystems are less biologically productive and diverse than those farther south • Variety of contaminants in food web; organochlorines detected in fish, mink, and Caribou	• Three major hydroelectric developments; environmental effects have included: - altered streamflow patterns - changed river ice conditions - deteriorated aquatic habitat through methylmercury in reservoirs - shoreline erosion	• Human population is small; 60% is Aboriginal • Residents consume large amounts of country food and thus are susceptible to low levels of contaminants in food chain

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Table 16.1 (continued)

Are environmental conditions in Canada becoming more sustainable?

Ecozone/ ecozone grouping	Selected trends grouped by World Conservation Strategy goals			
	Maintain life support systems	**Preserve biodiversity**	**Sustainable use of species and ecosystems**	**Improve human health and quality of life**
Taiga (continued)	• Mineral potential is high in much of Taiga; environmental effects of mining are localized; acidic mine tailings; low-level radioactive tailings (northern Saskatchewan) and air quality problems in Yellowknife • MEND program helping to deal with acid mine drainage		- interference with fish movements	• Measures to reduce/avoid consumption of mercury-contaminated fish • Much of Taiga under comprehensive land claim agreements, giving Aboriginal people a greater say in environmental issues
Arctic 28 000 people GDP $540 million	• Effects of climate change likely to be pronounced, especially in the western Arctic • Arctic haze; LRTAP from North America, Europe, and Asia (e.g., toxaphene in Turbot) • Contaminant levels (lead, lindane, and other organochlorines) declined • Contaminant levels highest in marine ecosystem (PCBs, DDT, DDE, and toxaphene)	• Protected area network increased very little in 1990s • 8% of Arctic region in protected areas (200 000 km^2) • Conservation strategies: Arctic Marine, Inuit Regional, Yukon, Endangered Spaces • International agreements: Polar Bear (1973), Arctic Goose (1986) achieving results • Prominent contaminants in biota: mercury, cadmium, toxaphene	• Traditional economy, mining, and tourism are the major industries; all are dependent on the ecosystem and natural resources • 400 of 900 waste sites cleaned up	• Population to double by 2015 • Population 80% Inuit, who derive most nutrition from country food • Scientists have not determined if contaminants are harming Arctic ecosystem and affecting country food • Surface drinking water contamination; 50% of communities with no wastewater treatment; rest minimal treatment • Land claims settlement led to integrated decision-making
Urban Canada	• Average levels of major air pollutants declined 1979–1993, CO by 56%, SO_2 by 46%, NOx by 28%, and airborne particles by 38% • Ground-level ozone is the most serious urban air pollution problem • Extent and level of municipal wastewater treatment have risen steadily, 1983–1994 • Canadians continue to own more cars and drive farther annually, contributing to a diffuse, low-density pattern of development	• Total green space covered nearly 50% of the built-up area of nine large Canadian centres (1991) • Green space/habitat is fragmented, thus reducing its use by wildlife • Urban spread encroaches on croplands, wetlands, and rural habitat	• Average daily household water use is high at 335 L per person (1994), but declined slightly from 1991 • Average energy use per person has declined slightly since its 1989 peak of 325 GJ per person, but remains high • Energy use per capita is lower in the inner city than in the suburbs • Canadians generate 1.7 kg of municipal solid waste per person per day (1992)	• Very small airborne particles (PM_{10}) are starting to be monitored and may be a health concern • Municipal solid waste discarded per capita declined by 16%, 1988–1992 • Many old contaminated industrial sites make the reuse of inner-city lands difficult and expensive • Consumption: Canada's ecological footprint averages 4.3 ha per person • On balance, Canadian cities are taking action on environmental sustainability issues

Note: Abbreviations used are as follows:

CO: carbon monoxide
DDE: dichlorodiphenyldichloroethylene
DDT: dichlorodiphenyltrichloroethane
GDP: gross domestic product
LRTAP: long-range transport of air pollutants
NAWMP: North American Waterfowl Management Plan
MEND: Mine Environment Neutral Drainage
NOx: nitrogen oxides
PCBs: polychlorinated biphenyls
SO_2: sulphur dioxide

[a] The population totals are for 1991 and refer only to the Canadian portion of each ecozone or ecozone grouping.

[b] In order not to double count, this population figure is for the Mixedwood Plains ecozone, which has a somewhat smaller area than the Great Lakes–St. Lawrence basin. This basin also includes a portion of the Boreal Shield ecozone and has a total population of 15.5 million.

production efficiencies and waste reduction strategies have generally continued to improve.

Ecosystems in Canada have also been heavily affected by forestry operations. However, forestry companies are increasingly adopting more integrated approaches to the management of forest ecosystems. These approaches take greater account of other uses of the forest by both wildlife and humans and are more ecologically sustainable than past practices. In British Columbia, a number of old-growth areas have received protection. New harvesting and reforestation practices (notably a reduction in the size of clearcuts) are also helping to limit impacts on those areas where cutting continues, although the practice of clear-cutting continues to be controversial. Further discussion of several of these initiatives can be found below and in Chapter 11.

Overall, the alteration of Canada's terrestrial ecosystems is proceeding at a slower pace than in the 1970s and 1980s. This trend is the result of both slower economic development and the adoption of more environmentally sensitive planning and management approaches.

The quality of Canada's water
Water quality for Canadians remains one of the highest environmental priorities, and progress has been made in cleaning up some of the country's most heavily contaminated water bodies. Initiatives such as Great Lakes 2000, St. Lawrence Vision 2000, and the Fraser River Action Plan have made a major contribution to these successes. Further progress can be expected with the development of management plans and pilot projects under the Atlantic Coastal Action Plan. There is also good news regarding levels of contamination in the Great Lakes–St. Lawrence basin. Phosphate control is succeeding, and Lake Erie, once considered beyond reclamation, is "alive" again. Concentrations of toxic chemicals are down, and fish and bird populations are recovering (e.g., Lake Whitefish and Lake Trout in certain Great Lakes [Hartman 1988] and Bald Eagles and Ospreys around the Great Lakes and the St. Lawrence River). At a Montreal drinking water plant, phosphate levels fell from an average of 0.03 mg/L in the early 1980s to near 0.01 mg/L at the end of the decade as a result of reductions in municipal sewage discharges upstream (see Chapter 6). Updated guidelines for Canadian drinking water quality have also been developed and approved by the federal and provincial health ministries (Health Canada 1996). The bad news is that some of Canada's water and sediments still contain many long-lasting toxic substances. Some 362 chemical substances have been identified in the Great Lakes, including some that are carcinogenic.

The contamination of groundwater is a growing problem. In a survey of 1 300 rural wells in southern Ontario, for example, 37% contained one or more contaminants at concentrations above the provincial drinking water objectives (see Chapter 10). Groundwater is most often contaminated by bacteria (from sewage) and salt (from highways). In agricultural areas, nitrates from fertilizers have become an increasingly significant source of contamination, as the use of nitrogen fertilizers increased from 2 t/km^2 in 1970 to 5 t/km^2 in 1990. Increased numbers of septic tanks associated with the sprawl of residential growth around metropolitan areas and runoff from livestock feedlots also contribute to groundwater (and some surface water) contamination (Commission on Planning and Development Reform in Ontario 1993). Contamination of groundwater with organochlorines (e.g., dry-cleaning solvents), pesticides, and hydrocarbons (from leaking underground storage tanks) is increasingly apparent (see Chapter 10). Remediation of this pollution is proving very difficult and expensive. As alternative sources of groundwater become more limited (because of pollution and drawdown), the seriousness of the problem will increase.

Some progress has been made in sewage treatment, but problem areas remain. As indicated in Chapter 12, nearly all of Canada's cities now have sewage treatment. The key exceptions are coastal cities, several of which continue to use the oceans for disposal of untreated sewage. According to Environment Canada's national environmental indicators, the proportion of Canada's population living in municipalities with sewers and served by primary treatment rose by 7.3% between 1983 and 1994, the proportion with secondary treatment by 2.7%, and that with tertiary treatment by 11%. The proportion with no sewage treatment plummeted from 28.3% to only 7.4% of the municipal population with sewers (from 5.2 million to 1.6 million) over the same period. Whereas only 100 000 people in the St. Lawrence basin were served by sewage treatment plants in 1985, there are now 2 200 000 with this service (see Chapter 6). Plans are now being made to construct new facilities for other areas, such as Greater Vancouver, where the level of sewage treatment has been inadequate. On the other hand, an initiative to clean Halifax Harbour has not succeeded, mainly because of cost. Halifax continues to discharge raw sewage directly into its harbour. Work is continuing to find a solution to this problem.

Maintenance of Canada's land base
The land base is essential to the production of food, fibre, and habitat for humans and other species. Although significant improvements have been made through programs and management practices, land degradation is a continuing problem, particularly in the Prairies ecozone, where it poses a threat to the economic vitality of the region.

Wind erosion remains a constant threat in the Prairies ecozone. According to Agriculture and Agri-Food Canada (1995a), 5 million hectares (or 15% of cultivated land in the Prairies ecozone) is estimated to be eroding by wind at more than the tolerable annual limit for soil loss. Water erosion is a more serious concern in the eastern half of the country, particularly in the Atlantic Maritime ecozone and the Great Lakes–St. Lawrence basin. However, between 1981 and 1991, progress was made in reducing the inherent risk of wind and water erosion through changes in land tillage practices, reductions in summerfallow, changes in cropping patterns, retirement of cropped land to permanent cover, and use of erosion control measures (Wall et al. 1995; see also Chapter 11).

Salinization threatens drought-prone areas in the Prairies ecozone, particularly where irrigation is practised. Most prairie agricultural land (62%) has less than 1% of its area affected by salinity, 36% has 1–15% of its area affected, and 2% has more than 15% of its area affected. Improved crop rotation and conservation practices have served to reduce the risk of salinization during the past 10 years (Eilers et al. 1995; see Chapter 11).

Brownfield sites — abandoned industrial sites where vegetation will not grow because of contamination — are another area of concern. No comprehensive inventory of such sites exists, although the growing use of site audits adds to the ability to identify the existence of contamination. Certainly, present-day industries are less prone to contaminate the land they use, but most cities have a large inventory of brownfield sites, most of which cannot be put to new uses until significant funds are spent to clean them. The growing role of environmental auditing and remediation is discussed later in this chapter.

Toxic contaminants

Levels of persistent toxic substances in living organisms in the Great Lakes and elsewhere have decreased significantly from levels in the 1970s and 1980s. Nevertheless, despite nearly 20 years of effort in Canada and the United States, the International Joint Commission (1993) reported that neither the goal of zero discharge nor that of virtual elimination of the input of any persistent toxic substance (including the 11 International Joint Commission "critical pollutants"; see Chapter 6) has been achieved in the Great Lakes.

Toxic substances, including both synthetic chemicals such as polychlorinated biphenyls (PCBs) and natural substances like mercury and lead, are present at low concentrations in water and especially in sediments in many of Canada's harbours, lakes, and rivers. High concentrations of these chemicals have been found in the tissues of many aquatic animals, particularly in the Great Lakes–St. Lawrence basin. Although concentrations of contaminants in the Arctic ecozones are generally lower than those in more densely populated ecozones, the potential impact on human consumers of country food is of concern and has resulted in health advisories in certain areas for selected species (e.g., Lake Trout). It has become clear through new research that long-term exposure to even low levels of some toxic substances, and mixtures of these chemicals, can produce subtle neurobehavioural and developmental effects in both wildlife and humans (see Chapter 13).

Concentrations of some organochlorines (e.g., dichlorodiphenyltrichloroethane, or DDT; dichlorodiphenyldichloroethylene, or DDE; and PCBs) have declined significantly in Canada since the early 1970s, but these substances have not disappeared. In some areas, concentrations of these substances have reached a plateau, despite continuing reductions in their production and discharge both in Canada and in many countries abroad. This plateau effect is caused by several factors, including ongoing new releases in areas where they remain in use, recirculation of previously emitted contaminants, and bioaccumulation in the food chain. Consequently, concentrations of these substances remain at levels that are potentially harmful to some wildlife species. Some persistent toxic substances continue to be detected in humans. In 1975, for example, the average PCB concentration in samples of human breast milk in Canada was about 11 parts per million (ppm). In 1982, it rose to a peak of 26 ppm; by the late 1980s and early 1990s, it had reached a plateau near 7 ppm (see Chapter 6).

Toxic substances do not necessarily stay in one place. In particulate and gaseous form, they can be transported over long distances by atmospheric currents. Once deposited, the more volatile of these contaminants may evaporate again, reentering the atmosphere, and may be transported to yet more sites, a phenomenon known as the "grasshopper effect." It is now known that some persistent toxic substances found in Canada have originated in Mexico and Central America as well as Eurasia. For example, in Lake Superior (whose shores and drainage basin are pristine compared with those of the other Great Lakes), air deposition is the predominant source of contamination by dioxins and mercury and is at least as important as a source of PCBs as all other sources combined (see Chapter 6).

Canadian use of toxic substances can also affect global ecosystems through this and other processes. Migratory waterfowl, for example, have been destroyed by consuming lead shot and sinkers picked up from lake bottoms, although new regulations adopted in 1995 to replace the use of lead in shot and fishing sinkers are expected to reduce this danger.

The pulp and paper industry, which has been a major source of certain toxic chemicals, such as dioxins and furans, has made significant gains in reducing toxic substances in its effluent. For example, accumulation of these chemicals in crabs and other shellfish in the Pacific Maritime ecozone had resulted in fishery closures in the late 1980s. By early 1995, 120 000 ha of coastal marine habitat were closed to shellfish harvesting. In August 1995, the Government of Canada announced the reopening of 48 650 ha of these fisheries (e.g., the crab fishery at Howe Sound in the Strait of Georgia). Reopening was possible because of reduced dioxin and furan levels in shellfish tissues, following process changes by industry in response to new federal regulations. As a result of the regulation, dioxin and furan levels from pulp and paper mills across Canada were reduced, on average, by 98.5% between 1988 and 1994, which represents virtual elimination from this source.

Canadian pulp and paper mills have also made significant reductions in discharges of biochemical oxygen demanding (BOD) materials and in chlorine use. Nearly all mills were successful in meeting the pollutant limits of the *Fisheries Act* by the end of 1995. The Northern River Basins Study, undertaken between 1991 and 1996, reported that, historically, chlorine discharge and BOD materials had been contaminating the Peace and Athabasca rivers, causing harm to fish populations. The study also noted, however, that pulp mill discharges to Alberta surface waters had improved significantly between 1957 and 1992. During that period, BOD dis-

charges declined from 30 000 kg/day in 1957 to 15 000 kg/day in 1973 to 6 000 kg/day in 1992, while over the same period pulp production had increased nearly 10-fold (see Chapter 4).

Pesticide use remains an important although diminishing source of toxic chemical releases. Pesticide spraying by the forest industry has been significantly curtailed over the past 10–15 years, until it now accounts for only 2% of sales of all pest control products sold in Canada (see Chapter 11). The area treated by insecticides was reduced from 3 million hectares in 1982 to 256 000 hectares in 1993, as the industry turned to biotechnological solutions to its pest problems. Two-thirds of the forest treated in 1993 involved the use of biological insecticides.

Farmers are still the largest users of pesticides. However, a 1993 survey of agriculture in Ontario (Hunter and McGee 1994) reported that pesticide use declined from 7 200 t of active ingredient in 1988 to 6 200 t in 1993, a drop of 13.3%. The decline for the 10-year period from 1983 to 1993 was 28.3%. Nationally, fewer farmers are using agrochemicals, the land area to which they are being applied has become smaller, and fewer pesticides are being applied per unit of crop output. Also, newly developed pesticides are more selective, less persistent, and less toxic to nontarget organisms (Agriculture and Agri-Food Canada 1995b).

Nevertheless, the number of substances known or strongly suspected to be toxic continues to grow, a trend that reflects not only the discovery of additional environmental and human health effects but also greater efforts to measure and compile inventories of toxic substances. Under the *Canadian Environmental Protection Act* (CEPA), 44 suspected toxic substances or groups of substances on the Priority Substances List have been assessed, and 25 have been classified as toxic. However, the long-term effects of many other substances still require study, and it is unclear in many cases what concentrations of individual substances constitute acceptable risks. Tributyltin typifies the problem that these substances present. Used in antifouling marine paints to inhibit the growth of barnacles and other marine life on boat hulls, it has been found to leach out of painted surfaces and has been linked to the poisoning of shellfish consumed by humans (see Chapter 13).

Over 200 airborne substances have been identified as actually or potentially hazardous to the environment. Many have common sources in the industrialized world: benzene and toluene from gasoline, tetrachloroethylene from dry cleaning, and dichloromethane from degreasing operations are familiar examples. Others include pesticides, polycyclic aromatic hydrocarbons (PAHs) from combustion, and industrial by-products such as dioxins (see Chapter 10). Also of concern is the generation of toxic waste. Most of this comes from industrial or institutional sources, but, according to recent estimates, each Canadian household throws out 6.8 kg of toxic wastes per year (see Chapter 2).

The effects of our activities on life support systems

Canadians continue to leave a large ecological footprint on the planet. Indeed, it has been estimated that, if all humans on Earth used the same levels of energy and other resources as do Canadians, it would take three planet Earths to supply the resources for them (Wackernagel and Rees 1996; see Chapter 1). One way to reduce the ecological footprint is to make production processes more efficient. In addition, efforts are needed to reduce the degradation of ecosystems by contaminants.

Canada has made some significant strides in addressing many of the most specific and pressing issues relating to toxic contaminants and to emissions and discharges of other air and water pollutants. Compared with those in most other parts of the world, Canada's industries are clean, and Canada's air and water are becoming cleaner, too. However, this report has identified many areas where improvement is still needed, and the emergence of new concerns (e.g., fine particulates and new toxic substances) as well as continuing issues (e.g., ground-level ozone and atmospheric change) show the need for vigilance. Many of the most significant improvements occurred when a limited number of industrial polluters (such as pulp and paper mills and smelters) were mobilized to address specific contaminants. New production technologies have helped to promote sustainability immensely, particularly where these have brought economic benefits to industry and society by increasing efficiency while reducing environmental impacts. Overall, however, consumption of resources per capita remains very high, as does production of waste, despite reductions in that area.

The impacts of Canadians' activities remain concentrated in the regions where most of them live, although the effects can be observed in all ecozones. Consequently, the Great Lakes–St. Lawrence basin and the Prairies ecozone as well as the Lower Mainland region of the Pacific Maritime ecozone show the most intense symptoms of the stresses that inhabitants place on their environment. Even so, contaminants from these regions as well as those from other parts of the world can be found in the air, water, soils, and food chains of the most remote ecozones in the country. It is also becoming apparent that incremental changes, seemingly inconsequential by themselves, can have cumulative effects when interacting with other seemingly inconsequential changes. Researchers and policymakers are now recognizing that potential cumulative effects need to be examined when planning new activities.

Maintenance of biological diversity

Biological diversity, usually referred to simply as biodiversity, is a key indicator of the health of the planetary system and each ecosystem within it. It is the sum of all living diversity: the variety of ecosystems, the variety of species within those ecosystems, and genetic variation within those species (see Chapter 14). This diversity gives the biosphere the flexibility it needs to adapt to internal and external changes and is thus necessary to support the web of life on which all species depend — humans included. Unfortunately, both locally and globally, it is apparent that biodiversity is diminishing. Although precise estimates of biodiversity loss for

Canada do not exist, it is estimated that, globally, species are disappearing at a rate of somewhere between 1 000 and 10 000 times the evolutionary rate of extinction (Environment Canada 1995). This pace of loss is unprecedented in history and is largely related to human actions that remove or change the habitat conditions needed for species survival. Lack of data and disagreement over how biodiversity should be measured explain the imprecision of this estimate, but, even taken conservatively, the trend is significant.

Each ecosystem can be characterized by the mix of plant and animal species that use it for habitat. Natural systems range from the very complex (e.g., coastal wetlands) to the relatively simple (e.g., boreal forests). Each system exists in a form of dynamic equilibrium, providing for all resident species the needed nutrients, temperature, and media for life. As the planet becomes more dominated by human activities, and as natural systems are modified by human ones, the ecosystem attributes needed to support each species can be altered or eliminated. Biodiversity is, therefore, a barometer of the Earth's health as a whole. The protection of biodiversity necessarily involves the protection of special places through formal designation as parks and reserves. However, protection also requires the integration of stewardship concepts into the management of lands held privately and managed for other purposes.

Ecosystems cross boundaries of jurisdiction and ownership, and responsibility for them therefore rests in many hands. Unfortunately, biodiversity is not yet a common watchword for those who make land management decisions — from individual lot owners or farmers to senior government bureaucrats. Still, initiatives such as the Model Forest Program, operating in 10 major forest regions across the country, efforts by organizations such as Wildlife Habitat Canada, and the emergence of models such as landscape management approaches to farming are providing a foundation for biodiversity preservation (see Chapters 11 and 14). Educational materials based on recent research, monitoring, and reporting that focus on the concept of biodiversity and the means to preserve it are essential, however, if Canada's actions are to succeed.

Habitat and species at risk

In Canada, many species are known to be at risk, and researchers continue to add to the list of endangered, threatened, and vulnerable species. Nevertheless, it is difficult to interpret these trends because, to a great extent, the addition of species to these lists reflects the results of continuing studies (notably of plants, reptiles, amphibians, and invertebrates) rather than changes in abundance alone. Thus, although the total number of species listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is greater now than in 1991 (243 as opposed to 193), this fact cannot be used to conclude that more species are in peril. Of the species on the list in 1991, populations of several raptors (notably the Peregrine Falcon) have begun to recover, and several other bird species (mainly fish-eating species) appear to be less affected by persistent toxic substances in their food chains. The reduction in the agricultural, industrial, and domestic use of pesticides is also expected to reduce stress on many species. Of the species reexamined by COSEWIC, six have been delisted since 1991 (i.e., Baird's Sparrow, Cooper's Hawk, Eastern Bluebird, Great Gray Owl, Prairie Long-tailed Weasel, and Trumpeter Swan).

As the text of the United Nations Framework Convention on Biological Diversity points out, the alteration, fragmentation, and conversion of habitat remain the most pervasive threats to biodiversity. These threats occur principally in those ecozones where there is the most concentrated human activity. In Canada, habitat destruction through urban expansion and the effects of agricultural and forestry practices was documented in the 1991 report *The state of Canada's environment*, as were other threats, such as persistent toxic substances and the impacts of mining activities and megaprojects such as the construction of large dams (Government of Canada 1991). Although these threats remain, there are reasons to believe that the negative effects of these factors have been reduced in the past five years. A sluggish economy and government restructuring have forced the postponement or termination of many large projects. In addition, the federal government eliminated its support for megaprojects in the 1995 budget.

Of course, it would be folly to rely on economic recession to solve Canada's environmental problems. With a resurgent economy, many of these stresses will return, and greater attention to the management of economic activities in a manner compatible with environmental objectives will be essential. To some extent, this appears to be happening. With improved management and the availability of more environmentally benign technologies, for example, both the agricultural industry and particularly the forest industry are achieving production goals while using fewer chemical products per unit of production. In addition, it is clear that relatively new practices (such as conservation tillage, sustainable tourism, alternative forest harvesting methods, and integrated forest management) are having an effect on habitat management. Canadians in a number of other sectors are also moving towards managing resources in a more ecologically sound way. Interestingly, relatively few of these actions expressly address the goal of maintaining biodiversity. Instead, biodiversity may be one of several goals, often collectively described by such terms as "more sensitive regional development," "risk reduction," or "integration of environmental factors into decision-making."

A case of carrying capacity

Each ecosystem has an inherent capacity to support certain numbers and kinds of species, biogeochemical cycles, and life support processes. As a result, there is a certain limit to the ability of each ecosystem to sustain itself. Although minor alterations to ecosystems may not change the basic carrying capacity, major changes can. Major alterations of ecosystems, for example, may reduce or enhance the carrying capacity for wildlife. The damming of streams may improve an area's capacity to

provide aquatic habitat and support wetland species. The impoverishment of soils through poor agricultural practices may diminish soil nutrient supplies and biomass production.

Over the centuries, humans have increasingly altered the characteristics of ecosystems, the variety and quantity of biomass, and the interrelationships and synergies among the parts. Direct human actions on natural systems have affected biodiversity substantially. For example, human societies have cleared massive amounts of land to meet their needs for food and living space, but the effects of doing so on the ecosystem's capacity to support other species have generally been ignored. Indeed, species that interfere with human objectives have typically been eradicated as weeds or pests.

Under the Framework Convention on Biological Diversity, Canada has begun to incorporate the habitat needs of wildlife (from mammals and birds to invertebrates and vegetation) into planning and management processes (Box 16.2). Unfortunately, experts are only beginning to understand the sensitivity of most species to the changes that occur as a result of these processes. Individual species have very specific habitat requirements (such as undeveloped beaches, estuarine wetlands, or alpine meadows), and the availability of these unique environments is critical to their survival. Fragmentation of habitat also limits the accessibility and utility of these environments to the species that depend on them. Each species has its own habitat demands, and each attribute of that habitat is uniquely sensitive to disruption. It is becoming evident that efforts to estimate carrying capacity for human activities (such as tourism, forestry, food production, and waste absorption) must be undertaken as part of a broader approach that considers the needs of all species. The objective of maintaining carrying capacity in its broadest interpretation is central to the preservation of biodiversity.

We are now learning, however, that it may be impossible to define carrying capacity or to understand the complexity of stress–response relationships well enough to make decisions that do not risk serious damage to ecosystems. As a result, many scientists are urging alternative approaches to the planning and management of development. These approaches would incorporate greater understanding of the sensitivity of species to changes, use of the precautionary principle, application of risk management concepts, and the use of safe minimum standards. Several promising initiatives supporting this objective are identified in the following subsections.

Wetlands

Wetlands are increasingly understood to be a critical part of life support systems, not only for species that depend on them for food or for breeding habitat but for the entire food chain, including humans. Considered to be the most biologically rich of all ecosystems, wetlands have been under stress since Canada's initial settlement. Indeed, the building of many Canadian cities (e.g., Ottawa, Toronto, and Regina) has involved draining marshes, filling swamps, and turning rivers into canals. In much the same way, portions of the country's farmland have also been "reclaimed" from wetlands.

Traditionally, wetlands have been undervalued and often seen as a liability. As a result, much of the wetland area of the Great Lakes–St. Lawrence basin and the Prairies ecozone has been eliminated. The remaining wetlands in these areas are critical to maintaining biodiversity for large parts of the continent. Prairie wetlands are the most important breeding habitat for a majority of the continent's duck species. Wetlands in the Atlantic Maritime ecozone, Great Lakes–St. Lawrence basin, and Montane Cordillera ecozone serve as critical stops on the eastern and western flyways for migratory birds. Also, wetlands often provide the only variety in a human-dominated monocultural landscape.

A slowing of the vigorous pace of economic activity of the 1980s lessened pressures to convert wetlands to urban or agricultural uses between 1991 and 1996. Changes in farm subsidy programs, noted below in this chapter, have also reduced the incentive to fill or drain wetlands for crop production. Similarly, the tightening of environmental review procedures in some jurisdictions has tended to slow the rate of conversion of high-quality wetlands to other uses (Box 16.3). However, these procedures are increasingly under review, and some governments in Canada are now weakening their wetland preservation and regulatory activity, which may reduce the future levels of protection received by wetland systems.

Action by nongovernmental organizations and landowners has also helped to conserve wetland habitat. Spurred by the Permanent Cover Program (run by Agriculture and Agri-Food Canada from 1989 to 1994) and by joint ventures under the

Box 16.2
Canada's commitment to the Framework Convention on Biological Diversity

Canada ratified the United Nations Framework Convention on Biological Diversity in December 1992. The convention's three objectives are:

- *the conservation of biodiversity;*
- *the sustainable use of biological resources; and*
- *the fair and equitable sharing of the benefits that result from the use of genetic resources.*

One of the key obligations for parties that have ratified the convention is the preparation of a national strategy for preserving biodiversity. The Canadian Biodiversity Strategy is a response to this obligation and has been developed as a guide to implementing the convention in Canada. The strategy's vision statement encourages the development of Canada as "a society that lives and develops as part of nature, valuing all life, taking no more than nature can replenish and leaving to future generations a nurturing and dynamic world, rich in its diversity of life" (Environment Canada 1995).

North American Waterfowl Management Plan (NAWMP) — discussed below in the section on progress towards sustainability — many farmers have acted to reduce the conversion of wetlands in the Prairies ecozone and to begin habitat enhancement projects. In fact, as a result of NAWMP initiatives from 1986 until the end of 1995, over 2.5 million hectares of wetland and upland habitat in Canada (including drainage areas, feedstocks, and breeding areas, often under private ownership) were secured and enhanced or had their uses modified to support the objectives of the plan. Of the 560 000 ha that were secured and enhanced, the majority were located in the Prairies ecozone (NAWMP 1996).

Exotic species

The introduction of exotic (i.e., nonnative) species can both directly affect native species and cause changes to their habitat. Indeed, next to loss of habitat, the introduction of these species is the leading cause of biodiversity loss.

The Zebra Mussel, accidentally introduced into the Great Lakes in the mid-1980s, has had a substantial effect on the populations of other molluscs (eight species have been extirpated in Lake Erie). It has also depleted food supplies for fish and limited the availability of natural surfaces for spawning (see Chapter 6).

Purple Loosestrife has continued to spread through Ontario's wetlands and watercourses, providing strong competition for or even overpowering native species. Some success has been reported in the use of another introduced species (the beetle *Galerucella*) to control this weed. In 1992, two types of nonnative leaf-eating beetles were introduced into stands of Purple Loosestrife in Ontario; in 1993, a nonnative root-boring weevil was also introduced to help control this invader. Results of these experiments are positive, but the use of this approach is not in widespread use and remains controversial.

Concern has also been expressed over the emergence of "engineered species" and the establishment of suitable control mechanisms to prevent such species from affecting current systems. On the other hand, there have been promising advances in the use of biotechnology to develop bacterial species that can turn contaminants into more benign substances and bioremediate contaminated sites. An experiment is under way in Hamilton Harbour to use bioremediation on sediments, which would otherwise be very difficult to extract and clean. As well, bioremediation is increasingly being used commercially for sites contaminated by hydrocarbons, such as gasoline from leaking underground storage tanks.

Protected areas

There has been progress towards the goal of protecting at least 12% of Canada's area in its natural state and including a representative sample of each of the country's natural regions in the protected area. Between 1990 and 1995, the area under protection increased by about 15%, reaching almost 800 000 km² (see Chapter 14). This area represented approximately 8% of Canada's total land resource (an increase from approximately 7% in 1990). Consequently, a further 50% increase in the nation's land-based protected area will be needed to meet the overall 12% target. Of Canada's 217 terrestrial ecoregions, 160 contain at least one protected area, but only 51 of the ecoregions (23.5% of the country) have over 12% of their individual land area protected by some form of legislation (IUCN categories I–VI).

Major additions to the protected area system since 1991 include Aulavik National Park in the Northwest Territories (covering 12 200 km²), Vuntut National Park in the Yukon (covering 4 300 km²), and Wapusk National Park in Manitoba (covering 11 475 km²), as well as new provincially protected areas in Quebec and British Columbia. In 1992, the federal, provincial, and territorial ministers responsible for environment, parks, and wildlife committed themselves to completing Canada's network of land-based protected areas by the year 2000. In recent years, there has also been increasing recognition that protecting marine ecosystems is as important as protecting terrestrial ones.

Sustainable use of resources, species, and ecosystems

Consumption, production, and waste

Although Canadians make up a mere 0.5% of the global population, they consume a disproportionate amount of the world's energy, materials, goods, and services. Canadians' attitudes towards the environment and sustainable development are often influenced by the messages the market gives them, and many market messages are aimed at increased consumption, not at sustainable development.

The national "wish list" for material goods continues to grow, as an increasing array of goods and services is considered necessary by Canadians for a "decent" standard of living. These include such recent additions as personal computers, compact disk

Box 16.3
The Federal Policy on Wetland Conservation

The objective of the 1991 Federal Policy on Wetland Conservation is to "promote the conservation of Canada's wetlands to sustain their ecological and socioeconomic functions, now and in the future." Its goals include:

- *ensuring that there will be no net loss of wetland functions on all federal lands and waters;*
- *enhancing and rehabilitating areas where continuing loss or degradation has reached critical levels; and*
- *securing wetlands of significance to Canadians.*

The government has also pledged to develop exemplary practices in support of wetland conservation and sustainable use and to incorporate these into the design and implementation of federal programs. Ensuring a sound scientific basis for policy is another goal and is being promoted by research into the role of wetlands in the hydrologic cycle.

players, cellular phones, large-screen televisions, southern vacations, designer running shoes, and home security systems. Some goods, such as computers, may actually help to reduce each person's ecological footprint, because they can substitute for the use of natural resources such as paper or for activities that produce greater impacts. Other goods (e.g., motorized recreational vehicles) can expand the impact that an individual has on ecosystems. Many people would argue that most of these goods do not contribute to meeting basic human needs (see Chapter 2). Moreover, the consumption of resources in the production of a growing list of luxury items may compromise the ability of future generations to meet their needs. As already noted, the planet could not physically sustain its current population (let alone the projected increase) if everyone were to consume at the current level enjoyed by Canadians (Wackernagel and Rees 1996). Such levels of consumption must either fall or, more optimistically, be sustained by much higher levels of eco-efficiency in the production of goods and management of wastes.[4]

A number of positive developments may help to mitigate the levels of stress that each Canadian places on the environment. For example, more energy-efficient appliances and motor vehicles have helped offset the overall energy consumption associated with greater ownership and use of these items. There is also an indication that the trend towards large homes has ended, as changing demographics and a sluggish economy stimulate demand for smaller dwellings.

A strong indicator of consumption levels is the extent of solid waste generation and disposal. From a sustainability standpoint, waste material represents a resource that has not been fully used, and it is thus a reminder that further potential remains — through reductions of material inputs at source, reuse, and recycling — for lessening the need to extract and process new resources. Canadians are among the leading per capita producers of municipal solid waste in the world. In 1992, they generated 18.1 million tonnes of municipal solid waste, or 637 kg per person yearly (1.7 kg per person daily), of which about one-half came from residential sources (see Chapter 12).

Nevertheless, generation of municipal solid waste per person declined by nearly 5% between 1988 and 1992, while disposal to landfill or by incineration fell by almost 16% per person over the same four-year period. These trends parallel an overall 21% reduction in packaging in Canada for 1988–1992, as reported by the National Packaging Monitoring System. The decline in municipal solid waste disposal was matched by major gains in recycling and composting, which together accounted for 17% of Canada's municipal waste stream in 1992, up from 6% in 1988. Such gains have in part been stimulated by improved access to curbside recycling for a wide range of waste materials, initiation of community composting programs, distribution of home composters, and other municipal programs. Of the 642 municipalities that Statistics Canada surveyed in 1993, nearly three-quarters operated a recycling program. Despite these successes, the challenge of further reducing the municipal waste stream remains. Nearly 83% of municipal solid waste generated in 1992 was discarded, with 78% going to landfill sites and 5% to incineration (see Chapter 12).

On the production side, Canada's manufacturers have been important participants in the effort to address environmental issues. Manufacturing is a large part of Canada's economy and the source of many hazardous and toxic substances, particularly in such sectors as metal, leather, and chemical production. The regulation, collection, and disposal of a growing range of toxic substances remain a challenge for both industry and government. However, some notable successes have been achieved, including reductions in the use of packaging and in emissions of air pollutants, as well as the phasing out of ozone-depleting substances. New technologies have also helped Canadian industry to make better use of some wastes, as in the case of the forest industry, which uses waste wood and sawdust to make chipboard and shipping containers. In addition, waste exchanges, such as Winnipeg's exchange for used construction materials, are in operation in many Canadian cities and have proven to be a welcome innovation for many companies. Managers are finding that "secondary" raw materials, often available nearby, are an easy-to-obtain and less expensive alternative to traditional "primary" sources. This type of initiative demonstrates that good environmental management often makes economic sense.

The steel industry has been a significant source of persistent toxics and other pollutants. The industry has recently invested heavily in process improvements and pollution controls, reducing many of its emission streams by over 50% and some by as much as 98%. Recycled materials now go into half of the iron and steel produced in Canada. In addition to reducing the demand for new materials, metal recycling also produces substantial energy savings. Manufacturing a product from recycled steel uses 74% less energy than making it from new ores. The corresponding energy savings for nonferrous metals are as follows: aluminum 95%, copper 85%, lead 65%, and zinc 60% (see Chapter 11).

Canadians continue to be profligate in their use of water. However, many cities have benefited from changing their water pricing strategies. In cities that charge for water per unit used, water consumption is about 40% less relative to cities that charge a flat rate. The lower level of water use not only reduces the need and expense for larger water treatment facilities but also reduces the need for additional sewage treatment systems. Nevertheless, Canadian households continue to use

4. The World Business Council for Sustainable Development states that eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity, through the life cycle, to a level at least in line with the Earth's carrying capacity. This is achieved through improvements to material and energy efficiency of products, reductions in environmental and human health related impacts, designing products that "fit" into ecological cycles and can be easily disassembled and recycled, and extending the durability, service life, and functionality of products.

water in large quantities. Regionally, usage in 1994 ranged from 250 L to 450 L per capita per day. Although average home water consumption in Canada peaked in 1991 and has declined slightly to 335 L per person per day (1994), Canadians remain among the highest per capita users of water in the world.

Two noteworthy trends have come to light relative to waste and pollution management. First, as societies become more affluent, they tend to generate more waste. Second, as they become more industrialized, they tend to discard more of their wastes into air and less into water. Thus, many of the worst water pollution problems are to be found in less developed countries, whereas the air pollution problems occur in the developed world. As more countries become increasingly industrialized using current technology, we can expect more air pollution, particularly in nations that are in the early stages of industrialization. We can also expect the amount of waste produced to increase internationally. Although Canada still has considerable room for improving its own record, it also has developed successful responses that can serve as models of how to address waste management issues effectively.

Facing the full cost of resource use and management

The prices currently paid for goods and services do not always reflect their true cost in inputs, by-products, and external effects. For example, when a retailer sells gasoline, he or she is unlikely to build into the sale price the costs of the gasoline's contribution to global warming and ground-level ozone, the potential cost of respiratory disorders that are aggravated in people who breathe car exhaust, or the cost of damage to roadside flora. Thus, consumers do not pay for many of the indirect costs associated with gasoline use.

Similarly, the economic value of a resource often represents only a portion of its full value. Forests, for example, provide more than just lumber. They also retain water, act as carbon sinks, and supply a wide range of products and services, including habitat for many species and resources for recreation and tourism. Resources are also often undervalued, because the costs of depletion are overlooked. In the past, many people considered supplies of timber, fish, clean air and water, and agricultural land to be virtually unlimited. Individuals and industries tended to use all they wanted, because they believed there would always be plenty left. Improvements in science and the shock of unpleasant surprises (such as the depletion of Northern Cod stocks off Newfoundland and the subsequent closure of the commercial cod fishery) are beginning to cause a reexamination of attitudes towards natural resources and the real costs associated with their use.

As both a socioeconomic and an environmental concept, sustainable development requires decision-makers to consider the full costs of resource use, including costs that are not adequately reflected in the marketplace. Some of these, such as the cost of replenishing a resource or restoring a damaged ecosystem, may be quantifiable, but others (such as the aesthetic value of a national park) are harder to put a price tag on. Nevertheless, it is important that such nonmonetary costs and benefits be adequately weighted in making decisions about resource use. Certainly, a full accounting of such factors as resource replenishment and management, site cleanup, pollution control, waste management, and aesthetic impacts is likely to result in decisions (about the choice of production technologies, for example, or the protection of national parks) that will be very different from those based on market prices alone.

The application of full-cost accounting to economic decision-making, in concert with other environmentally sensitive management tools, holds promise for better resource management, to the benefit of not only those who make the decisions but also those whom the decisions affect, including people in other sectors and regions. Some companies are now beginning to apply these techniques — often as a result of participatory planning processes in which stakeholders have pushed decision-makers to consider environmental costs. Consequently, many sectors are making better efforts to manage the full life cycle of their products — from harvest or extraction to use and ultimately to disposal or recycling. The move towards fuller-cost accounting can also be seen in a variety of other developments, such as the adoption of deposit refund systems and increased tipping fees for waste disposal.

Sectoral trends in stress on the environment

Environmental analysis and management in Canada are still largely organized in terms of the activities of different economic sectors. Accordingly, this section addresses changes in the principal environmental stresses by sector (see Table 16.2), identifies the ecozones in which the stresses from each of these sectors are most concentrated, and notes progress towards sustainable management practices. Specific programs and initiatives are highlighted below under "Progress towards sustainability."

Agriculture

The use of more sustainable agricultural practices has generally increased across Canada, although problems remain. In the Prairies ecozone, there has been continuing concern about the removal of original cover through land clearance, continuing alteration of habitat through normal agricultural activity, and degradation of the soil. The emergence of conservation tillage (including no tillage) has reduced the level of stress on one-third of the land seeded in Canada, particularly in the Prairies ecozone. As well, a 27% reduction in summerfallow in the Prairies ecozone between 1971 and 1991 reduced the potential for wind and water erosion (see Chapter 11). The alteration or elimination of farm support programs and transport subsidies has also reduced the impetus to expand grain production by farming land unsuitable for continuous cropping. Programs such as the Permanent Cover Program have seen significant areas of former cropland returned to pasture, which better suits the capability of the land. Under this program, 0.5 million hectares of marginal cropland were returned to permanent cover on 15 000 farms between 1989 and 1994 (see

Table 16.2
Are our actions becoming more environmentally sustainable?

Human activity	Selected trends grouped by World Conservation Strategy goals: Maintain life support systems	Preserve biodiversity	Sustainable use of species and ecosystems	Improve human health and quality of life
Lifestyle, consumption	• Auto ownership per 1 000 has increased from 140 (1950) to 310 (1970) and finally to 484 (1994), leading to urban sprawl, loss of natural areas, and increased air quality problems • Trend towards larger vehicles, especially vans and light trucks, which tends to increase overall fuel use • Typical household estimated to produce 6.8 kg of hazardous waste per year (cleaners, paints, pharmaceuticals)	• Single detached homes continue to be popular; rose from 31.4% of national housing starts in 1971 to 52.8% in 1994, leading to spread-out cities and a corresponding loss of natural areas • Country living around Canada's largest cities is becoming more attractive; rural non-farm population increased from 3.74 million (1971) to 5.58 million (1991)	• Canadians' personal ecological footprint (area needed to produce resources to support lifestyle) is among the highest in the world (4.3 ha per person) • Household water use per capita per day (335 L) has declined slightly, but among the highest in the world • Energy use per capita has declined a little from its 1989 peak (325 GJ annually) but remains high • Increased acquisition of residential appliances leading to more electricity use	• Canadians produce large quantities of municipal solid waste (1.7 kg daily per person in 1992) • Disposal of municipal solid waste per person down 16%, 1988–1992, owing to increased recycling and composting • Transit rides per person annually declined from 246 (1950) to 100 (1970) and have remained fairly stable since then • Telecommuting is relatively small, but rising, with the potential to offset "journey-to-work" trips
Agriculture	• 5 million hectares estimated to be eroding by wind at more than the tolerable annual limit for soil loss (15% of cultivated land in Prairies ecozone) • Risk of wind and water erosion reduced through better cropping, tillage, and land management practices • Agricultural pesticide use declined 28.3% by weight (1983–1993), applied to a smaller land area	• Under Permanent Cover Program, 0.5 million hectares of marginal cropland returned to pasture (1989–1994) • Changes to agricultural support programs reduced incentives for expanding grain monoculture on land unsuitable for continuous cropping • Habitat enhancement on farms: over 2.5 million hectares secured, enhanced, or had their use modified to support NAWMP (1986–1995)	• Intensification of farming: total farmland stable (1971–1991) while total cropping area increased 20% • Conservation tillage (including no tillage) practised on 31% of land seeded (1991) • A 27% decline in summerfallow (1971–1991) reduced erosion potential • More efficient cropping reduced energy use per unit yield (i.e., soybeans, grain, corn)	• In some agricultural areas, nutrient surpluses (derived from nitrogen fertilizers, animal manure, and other sources) have been a contributing factor to groundwater contamination • Voluntary environmental farm planning initiatives are being advanced by farm groups in several provinces
Forestry	• Under new regulations, dioxin and furan levels from pulp and paper mills virtually eliminated, on average, 98.5% (1988–1994) across Canada • Significant reduction in biochemical oxygen demanding materials (42%) and suspended solids (41%) in pulp mill effluent (1988–1993) • Reduced forest pesticide spraying: from 3 million hectares (1982) to 256 000 ha (1993)	• Agreement on management of some old-growth forests (e.g., Clayoquot Sound) • Integrated pest management reducing the need for pesticides • Biotechnology helping to improve yields; use of Bt — biological pest control	• Annual forest harvest peaked at 0.5% of Canada's total timber-productive forested area in late 1980s • Clear-cutting is the predominant harvesting method at close to 90% nationwide, ranging from 80 to 99% by region; average size of clear-cut block reduced • In 1993, total cumulative area of forestland not successfully regenerated started to decline	• Model forests program: multiple use, community involvement in planning and management have potential for improved quality of life in nearby communities

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Table 16.2 (continued)
Are our actions becoming more environmentally sustainable?

Human activity	Selected trends grouped by World Conservation Strategy goals			
	Maintain life support systems	**Preserve biodiversity**	**Sustainable use of species and ecosystems**	**Improve human health and quality of life**
Forestry (continued)			• Sixfold increase in use of recycled paper in making paper and paperboard, and 25% increase in lumber produced from each unit of wood (1975–1995) • Criteria and indicators of sustainable forest management developed	
Fisheries	• Closing of shellfish beds because of contamination from sewage and other causes, 120 000 ha by 1995 • Some shellfish beds reopened (48 465 ha in late 1995) as dioxin and furan effluent declined • Long-range transport of pollutants resulted in fish contamination in remote areas (e.g., toxaphene in Turbot in Arctic)	• Much to learn about functioning of marine ecosystems, particularly concerning the food chain of commercial fish species • Resurgence of fish species in Great Lakes (e.g., Lake Trout, Lake Whitefish) caused by nutrient controls, catch limitations, Sea Lamprey control	• Collapse of Northern Cod stocks and declines in other Atlantic groundfish because of overfishing, environmental factors, and abusive fishing practices • Ability to harvest some marine resources exceeds sustainable levels owing to excessive labour and capital in the industry • Monitoring, assessment, and conservation of fishery resources are undergoing review and strengthening • Pacific Herring fishery best example of sustainable management of fish stocks	• Loss of cod and decline of Atlantic groundfish has serious socioeconomic repercussions for Atlantic Canada • Government support is maintaining some communities while they search for a new economic base • Advisories on consumption of freshwater fish in limited, specific areas has largely avoided serious health problems
Mining and metals	• Estimated 12 500 ha of acid-producing tailings, and 739 million tonnes of acid-generating waste rock in Canada (1994) • Cost of dealing with sites where acid drainage occurs estimated at $2–5 billion • Programs such as MEND and ARET have helped to reduce emissions and effluents	• SO_2 emissions fell 56% in eastern Canada (1980–1994), largely owing to reduced emissions from smelters • Programs reduce the environmental effects of mining (e.g., AQUAMIN) • Regulation now of reclamation of closed mine sites, but over 6 000 orphaned and abandoned tailings sites remain, some with environmental problems	• Iron and steel now have 50% recycled content, resulting in 74% energy savings • Energy savings arising from use of recycled materials in production of nonferrous metals are: aluminum 95%, copper 85%, lead 65%, and zinc 60%	• Mining is the economic mainstay for over 115 Canadian communities • Innovative strategies to prolong life of remote, resource-dependent communities (e.g., Whitehorse Mining Initiative Accord) • Successful recycling of nearly abandoned mining town into a retirement community (e.g., Elliot Lake)
Energy production and use	• Fossil fuels currently supply about 70% of Canada's energy requirements and contribute to three major air pollution issues: climate change, acidic deposition, and urban smog	• Many energy megaprojects have been cancelled or put on hold owing to financial, social, and environmental concerns	• Energy intensity of the Canadian economy declined 25% (1973–1985) but slowed to a 3% decrease (1985–1992)	• The largest energy efficiency improvements occurred in the residential sector (building code, retrofit) and transportation sector (fuel efficiency targets), particularly during the late 1970s and the 1980s

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Table 16.2 (continued)

Are our actions becoming more environmentally sustainable?

Human activity	Selected trends grouped by World Conservation Strategy goals: Maintain life support systems	Preserve biodiversity	Sustainable use of species and ecosystems	Improve human health and quality of life
Energy production and use (continued)	• Stabilizing energy-related greenhouse gas emissions at 1990 levels will be difficult — measures undertaken include the National Action Program on Climate Change and the federal Efficiency and Alternative EnergyProgram		• Total energy consumption in Canada has been rising since 1985 after a period of relative stability (1974–1984) • Options to reduce the environmental effects of energy production and use have included add-on technologies, "clean" energy technologies, improved energy efficiency, alternative fuel sources, and energy conservation by consumers	• Disposal of radioactive waste is a key issue of the nuclear power industry; a plan for permanent disposal of fuel waste undergoing public review • Ground-level ozone and its precursors contribute to a variety of health problems
Transportation	• CO_2 emissions from transportation have increased 400% since 1950, while Canada's population increased 100% • Transportation is responsible for significant releases of VOCs, NOx, CO, very small particles (PM_{10}), and benzene • The average new car in 1990 emitted only 24% of the NOx, 4% of VOCs, and 4% of CO of a new car in the early 1970s	• Use of the automobile has contributed to low-density, widely dispersed cities that encroach on agricultural, forestry, and habitat resources	• Average Canadian passenger vehicle (in-use fleet) improved 39% in energy use per kilometre (1974–1994) • New automobile fuel efficiency levels have virtually plateaued since 1988 • Auto ownership per 1 000 people has increased nearly 3.5 times since 1950 to 484 vehicles (1994) • Alternative transportation fuels supplied less than 2% of road transport demand in 1991, projected to increase to 4% by 2010	• Vehicle emissions contribute to some health problems (e.g., asthma) linked to air quality problems • Much urban design is based on facilities for vehicles • Transit rides per person annually declined 20% (1986–1992) from 111 to 88, after a modest increase in ridership (1979–1986) • Lower-income people relying on transit have mobility problems
Outdoor recreation and tourism	• Tourism is growing and places increased pressure on the fragile ecosystems that draw visitors • More visits to national parks, from 12.5 million to 14.2 million people (1989–1993), are placing pressure on the infrastructure and ecosystems	• Protected areas in Canada have increased to 8% of total area (IUCN categories I–VI) • The parks system (national, provincial, local) does not include sufficient habitat to sustain all native species • NAWMP and other programs protect migratory waterfowl habitat	• Sustainability of outdoor recreation (e.g., sports fishing) depends on ecological health of fish habitat and effective regulation • Recreational fisheries in many lakes affected by acid rain and toxic substances • Restocking occurs in many heavily fished lakes and rivers	• Many communities rely on tourism and outdoor recreation as a major part of their economy

Note: Abbreviations used are as follows:

AQUAMIN: Assessment of Aquatic Effects of Mining in Canada
ARET: Accelerated Reduction/Elimination of Toxics
Bt: *Bacillus thuringiensis*
CO: carbon monoxide
CO_2: carbon dioxide
IUCN: World Conservation Union
MEND: Mine Environment Neutral Drainage
NAWMP: North American Waterfowl Management Plan
NOx: nitrogen oxides
SO_2: sulphur dioxide
VOCs: volatile organic compounds

Chapters 4 and 11). While total farmland has remained stable since 1971, the crop area has continued to rise, indicating that the most productive land is being used more intensively.

Forestry

Between 1975 and 1993, over 14 million hectares of forestland in Canada were harvested. Of this area, 11 million hectares have been successfully regenerated to commercial species. Clear-cutting was the principal harvesting method in all ecozones where forestry was undertaken and was used on 80–99% of the harvested area. The annual harvest has peaked at about 0.25% of Canada's forested area (about 1% of the timber-productive forest), compared with almost 2% that is affected by fire in a severe fire year and nearly 4% that may be affected by insect infestation at any point in time. As noted in Chapter 11 and in the section on life support systems in this chapter, there has been a significant reduction in the use of pesticides in the forest. There has been a growing focus by the industry on forest ecosystems, on multiple uses of forests, and on improved conservation methods. Also, most areas have seen changes in harvesting techniques, with a reduction in the average size of clear-cut blocks and increasing use of alternatives to clear-cutting that contribute to natural regeneration.

The state of Canada's environment — 1991 reported that the percentage of cut area that was successfully regenerated had risen from 66% in the mid-1970s to about 80% in 1988 (Government of Canada 1991). Data for 1992 reveal that annual restocking of harvested area still remains near 80% but that increased efforts have been made to regenerate some of the formerly unstocked areas to commercial species. This has had the effect of reducing the cumulative amount of nonregenerated forestland (which had increased annually over the past two decades). The amount of waste in wood and fibre has also been greatly reduced through more efficient use of primary product.

However, concerns over forest management practices remain. A large segment of Canadian society considers clear-cut harvesting unsustainable and objects to its continuation. Another flash point is the continuing depletion of old-growth forests through harvesting, particularly old growth associated with the coastal temperate rain forests of British Columbia. As the old growth diminishes, so does the unique habitat and the range of species that it supports. Overall, maintaining forest biodiversity depends on maintaining a range of forest types, functions, ages, and distribution patterns across the landscape.

Fisheries

One of the most striking environmental events of the past five years was the near disappearance of the Northern Cod and the ensuing closure of Newfoundland's cod fishery. The collapse of the cod stocks was followed by abrupt declines in many other Canadian Atlantic groundfish stocks and closures of these fisheries. These events, with their serious repercussions for the economy and communities of Atlantic Canada, have caused a reexamination of the sustainability of other fish stocks on both the Atlantic and Pacific coasts. The loss of the cod, the mainstay of Newfoundland's coastal economy, is largely attributed to Canadian and foreign overfishing. Despite intensive monitoring of stocks, the catch clearly exceeded sustainable levels. However, environmental factors (such as unusually cold water conditions and changes in predator and prey populations) and abusive fishing practices (such as discarding and underreporting) also contributed to the depletion of stocks. The ability to harvest some marine resources (due to excessive amounts of labour and capital in the industry) exceeds sustainable levels. Assessment, monitoring, and conservation of fishery resources need strengthening. Many contend that quotas were set too close to production and spawning levels and that insufficient attention was paid to other factors affecting the stocks. It is increasingly understood that management approaches should allow greater margins for natural fluctuations and other influences, thus providing a greater buffer should calculations or assumptions about the stocks be inaccurate.

In contrast to the significant decline in northwest Atlantic groundfish such as Northern Cod, catches of pelagic fish (e.g., herring, mackerel) have been stable except for a marked decline in Capelin, while landings of shellfish increased steadily from the 1980s to the 1990s. However, increased fishing pressure is being placed on fish species such as Turbot as well as on certain crustacean species, such as lobster, for which landings have recently declined. With the exception of the shellfish industries, pollution and habitat degradation do not appear to have had a major impact on marine fisheries. Industry and government are responding in a variety of ways to the problems of excessive labour and capital in the fisheries. Reduction of fishing licences and other management actions (such as shortened seasons, changes in quota limits, reductions in by-catch, and restrictions on the use of specific fishing methods) are being used to reduce pressure on other fisheries. As well, a rapidly growing new aquaculture industry has emerged that is to some extent compensating for the decline of natural stocks and helping to replace jobs lost by reductions in the fishery.

While selected conservation measures are currently under consideration as a result of recent drops in some salmon runs (notably the Sockeye Salmon run on the Fraser River), most salmonid stocks on the Pacific coast, except Coho and Chinook salmon, are believed to be in good condition for now, although data reliability remains an issue (see Chapter 3). There is a clear need for an improved early-warning capability if surprises about fish stocks are to be avoided. The Pacific Herring fishery seems to be the brightest example of sustainable management of fish stocks. Good assessment techniques and conservative management have generally kept harvesting levels of herring in line with stock productivity from the 1970s to the 1990s (Environment Canada 1994).

Mining

Environmental stress from mining activity has been reduced, partly because of a lessening of activity but more importantly because of better control of several of the

sector's impacts. Since 1991, the mining sector has reported reduced exploration and limited growth in most parts of the country, except for the Arctic and Taiga ecozones. It remains, however, an important sector, accounting for 16.4% of Canada's exports in 1995 and serving as the primary employer in 115 communities. Responding to stricter regulation and through its own industry initiatives, the mining sector has reduced discharges of pollutants, particularly heavy metals. Smelting of metal ores is still the largest source of sulphur dioxide in Canada and accounted for 50% of total eastern Canadian sulphur dioxide emissions in 1994. However, sulphur dioxide emissions fell by 56% in eastern Canada between 1980 and 1994, largely as a result of process changes and successful emission controls in smelters. Emissions from the Falconbridge nickel and copper plant in Sudbury, Ontario, for example, fell from 2.3 kg/kt of metal in 1980 to 0.96 kg/kt in 1994 (see Chapter 11).

Tailings piles and acid mine drainage, the legacy of past mining activities, remain an environmental threat. Acidic drainage is the most serious environmental problem facing the global metal industry. As of 1994, there were an estimated 12 500 ha of acid-producing tailings in Canada and another 739 million tonnes of acid-generating waste rock. The cost of dealing with sites where acidic drainage occurs is estimated to be $2–5 billion (see Chapter 11). Promising techniques for preventing or controlling acid mine drainage have been researched and developed in Canada by industry and government under the Mine Environment Neutral Drainage (MEND) program. Although regulations now require the reclamation of mine sites when they are closed, over 6 000 known orphaned and abandoned tailings sites remain, some of which present serious environmental problems. As well, environmental audits are continuing to reveal further areas with contamination associated with past mining and other industrial activities. These areas represent a serious liability, an environmental debt from the past that will eventually have to be repaid.

Energy

Canada has one of the most energy-intensive economies and one of the highest per capita rates of energy use in the world. There are several reasons for this: a cold climate, a high standard of living with heavy reliance on private cars, large numbers of single-family homes, an energy-intensive industrial base, relatively low energy prices, and high transportation demand as a result of a large land area and low population density.

From 1973 to 1985, the energy intensity of the Canadian economy (defined as energy consumption per unit of economic output) declined by 25%, largely as a result of energy efficiency improvements stimulated by the oil price shocks of 1973 and 1979. The biggest improvements in energy efficiency were recorded in the residential sector, as a result of new building code standards and government incentives to retrofit older homes in the late 1970s, and in the transportation sector, where they were prompted by federal fuel efficiency targets set in the mid-1970s (see Chapter 11). From 1985 to 1992, however, the energy intensity of Canadian economic activity decreased by only 3%. Indeed, after remaining relatively stable from 1974 to 1984, total energy consumption in Canada has been rising since 1985. Concerns about price and security of supply apparently no longer provide the powerful incentive to conserve energy that they did in the 1970s and early 1980s (Kowalski 1992; see also Chapter 11).

Fossil fuels (petroleum, natural gas, and coal), which currently supply about 70% of Canadian energy requirements, are major contributors to three of the more important air pollution issues: climate change, acidic deposition, and urban smog. While significant progress has been made on reducing acidic deposition, progress on the other two issues has been more elusive. A number of largely voluntary programs have recently been implemented to promote energy conservation, energy efficiency, and the use of alternative energy (described below under "Controlling pollution"). However, whether these will be sufficient to offset projected increases in energy use (Natural Resources Canada 1993, 1994; National Energy Board 1994) remains an open question (see Chapter 15). Periodic review of these new measures will be undertaken (Canadian Council of Ministers of the Environment 1995).

Options for reducing the environmental effects of energy production and use fall into five categories: add-on technologies, "clean" energy technologies, improved energy efficiency, substitution of more environmentally benign energy sources for fossil fuels, and energy conservation by consumers (see Chapter 11). Add-on pollution control technologies (such as scrubbers at power generating stations and catalytic converters on cars) have contributed significantly to reducing energy-related pollution. Clean energy technologies (e.g., high-compression, lean-burning engines), however, have not achieved their full potential to reduce energy consumption. Improvements in energy efficiency and fuel substitution (e.g., low-carbon natural gas for high-carbon oil and coal) can initially help to stabilize carbon dioxide emissions, but the longer-term reductions in carbon dioxide emissions necessary to stabilize carbon dioxide concentrations can only come from greater reliance on alternative and renewable energy sources and significantly greater energy conservation efforts. Unfortunately, many of the demand-side management programs being pursued by utility companies in the early 1990s have now been reduced as a result of severe fiscal restraints.

Megaprojects represented a large part of energy sector impacts in the past. The past five years, however, have seen a progressive slowing of such projects, as proposed hydro developments such as Grande Baleine and Kemano II have been put on hold. Construction of new fossil fuel and nuclear generation facilities has also virtually stopped. This slowdown can be attributed to the recent economic downturn and conservation efforts as well as to the federal government's decision to withdraw its support from megaprojects.

Nuclear power provides 19% of Canada's electricity and nearly 60% of Ontario's. A key environmental issue for the industry

remains the disposal of radioactive nuclear fuel waste. There are now 3 500 m^2 of highly radioactive waste stored at reactor sites. Because of the difficulty of dealing with these wastes and the problem of escalating construction and maintenance costs for reactors, nuclear power has not assumed the position of prominence in the economy that was once expected. No new nuclear power plants have been built in Canada in the last decade. Currently, all of Canada's nuclear fuel waste is safely stored in pools or in above-ground canisters at the reactor sites and is regulated by the Atomic Energy Control Board. After many years of development, a plan for the disposal of nuclear fuel waste in the geologically stable formations of the Canadian Shield is now undergoing public review. A Federal Environmental Assessment Review Panel will make recommendations on the safety and acceptability of this proposal in 1997.

Outdoor recreation and tourism

Outdoor recreation and tourism are growing industries, and some activities in this sector directly target fragile ecosystems, small attractive communities, and protected areas. In recent years, stresses on some of the most popular attractions have resulted in damage to fragile mountain ecosystems (such as alpine meadows) and alteration of the character of many other sites. Worldwide, the industry is discovering that its own success can damage the very attractions it seeks. Canada's national and provincial parks, which draw visitors from around the world, are no exception. Parks such as Banff, Point Pelee, and Forillon have had to develop new approaches to zoning and visitor control to mitigate the effects of growing tourist numbers.

Outdoor recreation and the income it generates depend on the preservation of healthy ecosystems. Sport fishing, for example, is one of Canada's most popular recreational activities and brings significant economic benefits to the national economy. The 1990 Survey of Recreational Fishing noted that nearly 5 million Canadian and 900 000 foreign anglers fished for 67 million days and spent $8.1 billion on goods and services directly associated with the sport (see Chapter 11). The sustainability of sport fishing depends on the ecological health of fish habitat and effective regulation of the activity. Controls on the release of sewage and industrial effluent have helped to maintain or improve many fish habitats, but large numbers of lakes remain less productive than they were before being affected by acidic deposition and persistent toxic substances.

Because tourism and recreational activities have the potential to harm the communities and ecosystems on which the prosperity of the industry depends, many tour operators and governments are looking at ways to protect Canada's comparative advantage as a clean, green, and unspoiled destination. Efforts include the promotion of ecotourism and the establishment of new protected areas. Ironically, the act of designating a park tends to increase the number of visitors, thus placing new pressures on the very ecosystem that is being protected. Some authorities have responded to this dilemma by limiting the number of visitors (as in the case of the West Coast Trail on Vancouver Island) or by preventing access altogether (as has happened with the Burgess Shale near Field, British Columbia).

Transportation

With its large land area and small population and its dependence on a global economy, Canada depends heavily on an extensive transportation network to move its goods and people. However, that dependence comes at a high environmental cost. Transportation consumes large amounts of energy, virtually all of which comes from fossil fuels, a highly polluting and nonrenewable resource.

One of the most important determinants of Canadian transportation use is the design of Canadian cities, which has made urban residents dependent on the automobile. Over the past several decades, the growth of Canadian cities has followed the North American trend, with large numbers of single-family dwellings being built on comparatively large lots. Surprisingly, in most Canadian urban centres, up to 50% of the land is green space — in the form of parks, boulevards, schoolyards, lawns around industrial centres, riverbanks, floodplains, vacant land, and other features and amenities. While this amount of green space has many positive benefits, it is also a factor in the dispersed development pattern that has augmented private vehicle use. Although regulations are starting to change, current zoning ordinances and housing preferences that encourage the development of residential subdivisions with spacious lots and large road allowances in places separate from shopping, business, and industry have made the journey to work lengthy for most people (see Chapter 12). Such low-density development has hindered the development of the type of public urban transportation facilities common in Europe and Japan and reinforced the reliance of Canadians on the automobile.

Canadians are second only to Americans in their per capita use of the automobile and air travel and are becoming less inclined to use more energy-efficient modes of transportation such as buses and trains. In terms of the percent share of total Canadian passenger transportation activity, the use of buses and trains declined by over 55% between 1950 and 1994 and by over 25% between 1980 and 1994 (see Fig. 11.46, Chapter 11). With many jurisdictions now reexamining public transit services after suffering financial losses from their operation, this trend may continue and could result in even more reliance on the automobile as the main mode of urban transport for Canadians in the short term. Although environmental groups continue to press for reduced automobile use and municipalities are considering a wide range of actions to encourage alternative modes of urban travel, most initiatives are still at the talking or planning stage (see Chapter 11).

The development of more energy-efficient vehicles and less polluting fuels has reduced the environmental impacts of automobiles, but these reductions have been largely offset by continuing increases in their number and use. As yet, research into alternative fuels and energy sources has not yielded marketable solutions to problems such as greenhouse gas emissions. Moreover, the majority of Canadians do not appear ready or able to reduce their

dependency on the automobile: most people's lifestyles are auto-dependent. A worker may have only half an hour to reach a second job across town. Spouses work in different parts of the city. Children must be left at daycare. Places of work are frequently outside the urban core and thus outside the range of public transit. These lifestyle choices and stresses all contribute to the continuing reliance of Canadians on the automobile.

Summary: Choices for reducing impacts on resources, species, and ecosystems

Determining where the limits lie in the use of resources, species, and ecosystems remains largely a process of trial and error. Nevertheless, problems such as depleted fish stocks, soil erosion, and polluted drinking water can, if carefully evaluated, teach lessons from which benefits can be obtained in the future. Where specific goals or regulations have been established, Canada's performance has been strong. Emissions of sulphur, lead, dioxins, and furans, for example, have been greatly reduced; the production and use of CFCs are being phased out; the output of solid waste has decreased; and more protected areas have been created. Given clear choices, Canadians as individuals, groups, or managers of institutions have often taken significant strides towards sustainability, in many cases achieving environmental and economic goals in tandem.

Costs can be an important constraint on actions to reduce effects on the environment, but such actions may also produce important economic benefits that partially or totally offset the costs of implementing them. Process changes that reduce industrial pollution, for example, often result in lower costs per unit of output, producing economic dividends for the companies that invested in the changes and an environmental dividend for society. Similarly, more ecologically sensitive land use planning can reduce construction costs by eliminating the need for extra infrastructure to deal with expensive environmental obstacles such as wetlands. "Green" products also make marketing sense. Consumers are often willing to pay a premium for products that are ecologically sound.

It should be noted, however, that many of the most obvious benefits from greening have already been gained, largely because the actions taken so far have been the easiest, both from a technical and an economic point of view. Future actions may be much more difficult to implement, not only because of the economic costs but also because of their effect on our current lifestyles. The habits, expectations, and consumption levels of Canadian society have not changed significantly, and it is still not clear whether Canadians, through either their individual choices or their support of government regulations or economic instruments, are willing to incur the economic and lifestyle costs that may be necessary in the long run if they are to live within their environmental means. Consequently, progress towards the third World Conservation Strategy goal, the sustainable use of species and ecosystems, may be slower over the next five years than it was in the past five.

In the long term, though, money spent now will prevent much higher outlays in the future. Just as it is much less expensive to inoculate children against infectious diseases than to treat them when they become ill, it is also much less expensive to control pollution before it is emitted than to clean it up or mitigate its effects afterward. Even more important is the fact that contamination left in the environment does not remain inert: chemicals migrate through air, soil, and water. The cost of remediating contaminated sites will only continue to grow if the sites are not managed at an early stage.

Finally, there are issues of intergenerational equity that must be addressed. Can a high level of consumption of nonrenewable resources be justified if inadequate supplies are left for succeeding generations? Can citizens ask their children to clean up pollution that previous generations have left behind in their haste for comfort? Can Canadians afford to take decisions without the representative of the seventh generation at the table?

Risks to quality of life, health, and community

Much of the attention given to environmental issues involves considerations of risk. Issues such as environmental contaminants and resource depletion are of particular concern because of the risks they pose to such basic requirements for human well-being as health and economic security. The 1996 *State of Canada's environment* report has revealed a number of areas where environmental issues are having very important effects on human well-being. These are summarized in the following paragraphs.

Risks to human health

Threats to human health in which environmental factors play a critical role include exposure to toxic substances (many of which do not occur naturally in the environment), disease-causing organisms in the environment (such as tuberculosis and Legionnaires' disease), and rapid international transmission of antibiotic-resistant and pesticide-resistant organisms (such as the Hanta virus and new strains of malaria). Canadians are generally less affected by environmentally transmitted diseases than are residents of most other parts of the world. However, the long-term exposure of many Canadians to low levels of persistent toxic substances continues to be a concern. These include both synthetic chemicals such as several of the organochlorines and natural substances such as heavy metals.

Many organochlorines, including PCBs, dioxins, and atrazine, are now known to mimic hormonally active (endocrine) compounds such as estrogen, growth hormones, and other steroid molecules. Research has shown that these substances are strongly implicated in the disruption of the normal balance of hormonal activity in laboratory animals and in wildlife, although it remains to be determined whether this mechanism also accounts for similar health effects in humans (Colborn et al. 1993; see also Chapter 13). This large family of chemicals includes many compounds in common household and commercial use.

Mounting evidence continues to reinforce concerns about the effects of these and other persistent toxic substances (International Joint Commission 1993, 1994). Long-term exposure of fish, other wildlife, and humans to these substances has been linked to reproductive, metabolic, neurological, and behavioural abnormalities as well as to immunodeficiency, increasing levels of breast and other cancers, and reproductive and intergenerational effects. Many of the effects are subtle and long-term and do not necessarily involve acute illness or death.

Much of the supporting science for this analysis is new, and some have argued that action to eliminate these substances from the environment should wait until conclusive proof of these effects is available. Others, however, have argued that waiting for such proof is unacceptable, because the potential effects are so critical that any delay in action could result in serious or even irreversible damage to human and wildlife populations. As a result, there is a continuing debate over the degree of precaution and the weight of evidence that should be applied to public policy governing the manufacture, use, disposal, and incidental generation of persistent toxic substances (see Chapter 13).

Another emerging problem is the increasing ineffectiveness of many pesticides and antibiotics as a result of the evolution of resistant strains of the organisms against which they are targeted. Although the emergence of these chemically resistant strains is a natural evolutionary process, it has been accelerated by the widespread use and misuse of both pesticides and antibiotics. Transmission of chemically resistant organisms is accelerated by the increasing international movement of people and goods. The number of air travellers, for example, has doubled in the last two decades. Even in countries like Canada in which chemical use is tightly regulated, organisms that have acquired resistance elsewhere, often as a result of the overuse of chemicals, are beginning to appear. Rapid global travel can also increase the risk of importing waterborne diseases such as cholera that are not normally found in Canada.

Airborne contaminants continue to be a factor in risk to human health. For most of the year, outdoor air quality in Canadian cities is generally within the acceptable range for pollutants covered by the National Ambient Air Quality Objectives — namely, sulphur dioxide, oxides of nitrogen, carbon monoxide, ozone, and suspended particles (see Chapter 12). However, about 200 airborne substances have been identified as environmentally hazardous or potentially hazardous, including, for example, benzene, toluene, and tetrachloroethylene. Average concentrations of such substances in outdoor air are between 2 and 10 times greater in cities than in rural areas, although industrial sites may have much higher concentrations (see Table 10.3, Chapter 10). Still, for most people, exposure to these toxic substances in indoor air, both at home and in the workplace, will be greater than exposure outdoors. Globally, tobacco smoke remains the source of pollution to which people are most exposed and the most costly in terms of disease and death (Brown et al. 1994, 1995). Some of the steps being taken by government and industry to control exposure to airborne contaminants are identified below in this chapter. Other efforts, such as limits on smoking in public spaces, replacement of potentially harmful building materials, and environmental audits of buildings, can also help to reduce exposure to potentially harmful substances within buildings.

It is increasingly obvious that there is no "away." The presence of persistent toxic substances in the Arctic food chain and of PCBs in albatross on the Midway Islands (in the central Pacific Ocean) demonstrates that there is no longer anywhere on the planet where synthetic chemicals are not detectable. Essentially, waste dumped into a river does not disappear; it can make its way back to humans in the water they drink or the fish they consume as food. Recently discovered phenomena like the "grasshopper effect" (see Chapters 6, 9, and 13) are helping to explain the dispersion of the by-products of human activity. Greater ability to measure very small concentrations of industrial chemicals is also helping to clarify the routes by which these substances end up in food and water, even though we believed we had disposed of them safely.

In Canada, the production and use of potentially harmful chemicals are greatest in the Great Lakes–St. Lawrence basin and in the Prairies ecozone, although a potpourri of potentially harmful substances from industrial solvents to household cleaners and pesticides is in common use in all ecozones. Risk of direct exposure to chemicals tends to be highest at industrial sites and in urban areas, but long-range transport by air and water and through the food chain exposes everyone to some potentially harmful substances. However, a rigorous food inspection system and effective water and wastewater treatment significantly reduce pathogenic and chemical risk to most (although not all) Canadians. As well, the establishment of consumption guidelines for fish and game from potentially contaminated sources is helping to reduce the risk of exposure to toxic substances.

Of particular concern are Aboriginal people who depend on the health and stability of northern ecosystems, as they derive most of their nutrition from country foods. Although there are higher than normal levels of contaminants in country foods, levels high enough to pose health risks are not widespread. Further studies are needed to monitor the long-term risks associated with the exposure of fetuses and breast-fed newborns to food chain contamination (Department of Indian Affairs and Northern Development 1996; see also Chapter 9).

Risks to communities

During the last 200 years, communities in Canada have often been subject to the results of resource depletion. The pattern of migration away from depleted or degraded areas has been repeated over and over again. Resource-based communities have come and gone as sawmills were closed (e.g., Ocean Falls, British Columbia), mines were closed (e.g., Elliot Lake, Ontario), and soils were depleted (e.g., the Opeongo Line in eastern Ontario). In the past several decades,

there have been continuing regional environmental and economic pressures resulting from the depletion or degradation of natural resources that have traditionally supported regional economies. In response, governments have created regional development programs to try to extend the lives of communities and make it possible for young people to stay and make homes in their birthplaces. Despite efforts to diversify local economies and develop new products and services, people have continued to move to large cities from places like Cape Breton, Gaspé, and the rural Prairies in the hope of finding jobs and an improved standard of living.

Many of the local economic problems have been the result of dependence on a single resource, the disappearance of which eliminated the economic basis for the community. New approaches to community planning and development that involve local residents seem to have promise in breaking the boom–bust cycle. Increasingly, communities are seeking diversification in recreation, tourism, manufacturing, and other areas, such as the high-technology and information services sectors, to reduce their risk of dependence upon a single resource.

How can communities sustain their own existence? Many communities, from the Avalon Peninsula to the Mackenzie Valley, have begun to come to grips with the question of what they wish to sustain, and many are choosing options that will prolong the life of the community and the jobs that depend on the resource base. Some innovative strategies have been identified to prolong the life of communities through improved management of the pace and sequence of renewable and nonrenewable resource development. For example, the Whitehorse Mining Initiative Accord seeks to minimize the consequences of mine closure on workers and communities by fully integrating plans for the life cycle of mining operations into the economic development plans of mining-dependent communities (see Box 11.15, Chapter 11). Many regional planning initiatives for northern ecozones are also considering plans that would use new or existing communities as nodes that could access a number of resources in sequence, rather than as temporary sites dependent on a single, depletable resource.

Some communities have been successfully recycled. Elliot Lake, a nearly abandoned mining town, for example, has been turned into a retirement community. Retirees have been attracted not only by the affordability of the housing but also by the level of services and the small-town atmosphere of the community. Recycling whole towns in this manner may be a model for the future. Several fishing communities in the Maritimes (e.g., Chester and Tatamagouche, Nova Scotia, and Shediac, New Brunswick) are explicitly seeking roles as retirement communities to replace their former economic dependence on fishing or forestry, as are some coastal towns in British Columbia (e.g., Chemainus and Gibsons).

Progress Towards Sustainability: Public and Private Policy and Program Initiatives

Canada is often viewed from abroad as a leader in the area of sustainable development, even though many at home continue to urge greater efforts in our own backyard. During the past five years, Canadians and their governments at all levels have continued to make progress in many areas, sometimes despite diminished financial resources and a reexamination of the role of government in delivery of services. Awareness of environmental matters remains high in the public's consciousness. Although the prominence of environmental issues may have peaked in the late 1980s and been eclipsed by economic and social issues in the 1990s, public opinion polls confirm that environmental conservation has become a core value for most Canadians.

This section surveys those areas in which Canadians are making progress towards sustainability, highlighting significant efforts, programs, and achievements since the last state of the environment report. The barriers to and opportunities for meeting environmental objectives are discussed, as are success stories that serve as models for future initiatives. At the same time, the demise or shrinking of many valuable programs and initiatives as a result of government spending cuts and deregulation is noted.

Table 16.3 summarizes a range of Canadian initiatives that contribute to sustainability at local, provincial/territorial, national, and international levels. Many of these initiatives are discussed in the following subsections, which correspond to the individual columns of Table 16.3. Table 16.4 summarizes progress by Canada towards specific international environmental commitments and national environmental goals.

Emerging themes: a context for Canada's environmental initiatives

A number of themes have emerged to guide the formulation and implementation of environmental policy in the public and private sectors. These include a general trend towards more holistic, ecosystem-based planning approaches, increased public involvement in decision-making, globalization of the economy and of communication, and a changing role for governments in achieving environmental goals as a result of a reduced emphasis on regulation and more limited economic powers. These themes provide a context for the discussion of progress and challenges that follows.

Ecosystem-based planning

Increasingly, governments, nongovernmental organizations, and communities are using a more holistic, ecosystem-based approach to resource management planning. The defining characteristics of ecosystem-based planning are that natural boundaries such as ecoregions, watersheds, or coastal zones are used as the basic planning units and that an attempt is made within these areas to deal with the interactions and linkages among environmental stresses and human goals simultaneously. The ecosystem approach contrasts with more traditional approaches, which have tended to deal with one type of pollution,

Table 16.3
Signs of progress: initiatives towards sustainability

	Selected examples of environmental initiatives						
Level of action	Resource management (renewables and non-renewables)	Conservation (living within our means)	Waste reduction (reduce consumption, minimize materials and energy)	Urban design (growth and form, technology and behaviour)	Pollution control (regulation and standards)	Payment of past environmental debts (cleanup)	Change decision-making (integration and education)
Individual, community, nongovernmental organization	• Stakeholder participation in resource management • Conservation provisions in Aboriginal land claims • Environmental farm planning • Conservation tillage and crop rotation	• Model Forests Program, 10 started (1992) • Private stewardship initiatives: e.g., Ducks Unlimited, Nature Conservancy, Wildlife Habitat Canada • Ontario Green Communities Initiative (18 centres)	• 2 million more households with access to recycling (1991–1994) • 70% of households with access to recycling (1994) • More household composting, 23% in 1994	• Community sustainability strategies (e.g., Hamilton's Vision 2020) • Alternative transportation strategies • Emerging trend to smaller homes • Action 21 program	• 40% of households with access to special depots for hazardous wastes (1994)	• Great Lakes Remedial Action Plans: 17 centres (Collingwood completed) • Community cleanups (e.g., Don River, Toronto)	• Healthy Communities Networks • Community environmental advisory committees • Projet de société • Canadian Global Change Program
Firm/industry	• Environmental codes of practice (mining, agriculture, forestry, tourism, petroleum) • Whitehorse Mining Initiative Accord • Effluent irrigation in agriculture	• Life cycle management of products • Production efficiency (e.g., less waste wood in forest industry) • Accelerated Reduction/Elimination of Toxics (ARET) program • Home energy audits by utility companies • Energy retrofits	• Green procurement • Industrial/construction waste exchanges • Pollution Prevention Pays program (3M Corporation) • Improving Manufacturing Environmental Performance program (Canadian Manufacturers Association)	• Green designed communities (e.g., Bamberton, B.C.; McKenzie Towne, Alta.; Cornell, Ont.) • Manage transportation demand (e.g., alternative work schedules and ride-sharing)	• Virtual elimination of dioxins and furans from pulp mill effluent • Major reductions of sulphur dioxide emissions from smelters • Reduced pesticide use in forestry and agriculture • Responsible Care® initiative (Canadian Chemical Producers Association)	• Environmental site assessments • New site remediation technology using bacteria • Underground storage tank cleanup	• Industry SOE reports (e.g., Ontario Hydro, Inco, Noranda) • Corporate environmental liability (insurers, lenders, and investors) • Environmental auditing and risk management • Sustainability indicators (forestry, tourism, and agriculture)
Local/municipal	• Municipal energy conservation management programs for buildings, vehicles, and street lighting • Natural heritage system: green zones, green corridors (e.g., Vancouver, Ottawa)	• Protection of ecologically significant areas (e.g., Toronto Waterfront Regeneration Trust) • Municipal water pricing by volume used • Demand management for transportation (e.g., parking control, ride-sharing, and telecommuting)	• Community composting • Waste audits • Conservation education for householders • Waste reduction targets set (Vancouver, Toronto, Montreal, and Sherbrooke)	• Policies for intensification of development, mixed land use, and compact housing forms • Promotion of energy-efficient transportation (e.g., bike lanes, local transit improvement)	• Municipal 20% Club (reduced greenhouse gas emissions in eight major centres) • Drinking water improvement planning (e.g., Vancouver) • New sewage treatment facilities completed (e.g., Montreal) • Reduced pesticide use on public green space	• Inventory of toxic sites in some centres • Harbour cleanup (e.g., Hamilton, Collingwood)	• Environment departments in some cities • Municipal SOE reports • Sustainable development strategies (e.g., Hamilton's Vision 2020, Task Force on Healthy and Sustainable Communities, Richmond, B.C.) • Ecosystem-based planning (e.g., Crombie Commission)
Provincial/territorial	• Smaller clear-cut forest blocks; increase in successful forest regeneration • B.C. forest renewal program and forest code of practice • Water management strategies, Prairies • Research/promotion of conservation tillage	• Prairie Habitat Joint Venture • Wetland conservation policies • New provincial and national parks • Clayoquot Sound Management Plan (B.C.) • Atlantic Coastal Action Program (13 areas)	• Provincial waste reduction strategies (e.g., Saskatchewan, Nova Scotia) • St. Lawrence Vision 2000	• Revised planning acts to strengthen environmental planning • Continued agricultural land protection acts (B.C., Quebec) • Building code improvements • Integrated regional planning (Greater Vancouver Regional District, Greater Montreal Task Force, Greater Toronto Area)	• Increased fines for polluters • Municipal/Industrial Strategy for Abatement program (re water pollution, Ontario) • Alberta Special Waste Treatment Centre (Swan Hills) • Northern River Basins Study (Prairies)	• Stronger laws for environmental liabilities • Provincial/local hazardous site inventories and cleanup	• Environment/economy round tables (four provinces) • Fraser River Environmental Management Plan • Native land claims settlements • SOE reports: five provinces, one territory, and Atlantic Region (covering four provinces)

continued on next page

Table 16.3 (continued)

Signs of progress: initiatives towards sustainability

Level of action	Selected examples of environmental initiatives: Resource management (renewables and non-renewables)	Conservation (living within our means)	Waste reduction (reduce consumption, minimize materials and energy)	Urban design (growth and form, technology and behaviour)	Pollution control (regulation and standards)	Payment of past environmental debts (cleanup)	Change decision-making (integration and education)
National	• Canadian Biodiversity Strategy (1995) • National Forest Strategy (1992) • Megaprojects moratorium • Alteration of farm support reduces cropping of unsuitable land	• Protected areas goal (12% of country) • Permanent Cover Program (agriculture) • Pacific Herring program • Atlantic Groundfish Strategy • Assessment of the Aquatic Effects of Mining in Canada (AQUAMIN) process	• National Solid Waste Management Program (CCME) • National Packaging Protocol (CCME) • Federal Efficiency and Alternative Energy Program (37 initiatives)	• R-2000 standard for home energy conservation • Innovative housing to promote infill, energy and water conservation (e.g., Healthy Housing Program) • Research re compact development and reduced infrastructure	• National Action Program on Climate Change • Canadian Acid Rain Control Program • NOx/VOCs Management Plan • National Pollutant Release Inventory • Toxic Substances Management Policy (1995)	• "National" Contaminated Sites Remediation Program • Federal facilities environmental database • Mine Environment Neutral Drainage (MEND) program • Federal siting task force on low-level radioactive waste	• New Commissioner of Environment and Sustainable Development • Greening of Government • New *Canadian Environmental Assessment Act* (1995) • Federal Pollution Prevention Strategy (1995) • National SOE reports and environmental indicators, and state of forests reports
International	• UN Framework Convention on Biological Diversity (1992) • UN Intergovernmental Panel on Forests • Transboundary fish stocks accords	• Arctic Environmental Protection Strategy (eight countries) • North American Waterfowl Management Plan (NAWMP) • Arctic Goose Strategy	• *Agenda 21*	• UN Habitat II Conference (1996)	• Montreal Protocol on stratospheric ozone depletion • UN Framework Convention on Climate Change • Canada–U.S.A. Air Quality Agreement	• Basel Convention on control of international shipments of hazardous wastes • Great Lakes 2000 program	• North American Commission on Environmental Cooperation • *Agenda 21* reports to UN Commission on Sustainable Development • ISO 14000 international environmental management system standards

Note: Abbreviations used are as follows:

CCME: Canadian Council of Ministers of the Environment

SOE: state of the environment

UN: United Nations

resource, or development at a time. Another significant feature of the approach is that it recognizes that the composition and needs of different ecosystems are distinctive. It has consequently given rise to a number of region-specific action plans such as those for the Fraser River, the Great Lakes–St. Lawrence system, and Atlantic coastal areas. The ecosystem-based planning approach also emphasizes interaction among affected stakeholders and has tended to diminish the relative importance of governments as the prime drivers and funders of public policy-making activity. As a result, it has encouraged a sharing of responsibility for projects with potential environmental impacts. Examples of the application of ecosystem-based planning range from projects under the Arctic Environmental Strategy to the rehabilitation of Toronto's waterfront.

Participation by stakeholders

Planning processes are increasingly involving a greater range of stakeholders. Community participation has risen in review processes for local plans, major projects, and remedial action plans. Stakeholders are now also routinely involved in the planning and implementation of major resource development projects. Participation has been driven by the need to consider the values of all stakeholders, meet legislative requirements, and create partnerships to bring in sufficient resources during times of fiscal restraint. Round tables have made an important contribution in broadening the base of participation in environmental and economic decision-making.

Over the past decade, round tables on the environment and the economy — at the federal and provincial/territorial levels — have served as catalysts for dealing with complex environment–economy issues and creating partnerships involving governments, industries, and communities. Although British Columbia and Ontario recently terminated the operations of their round tables, the National Round Table on the Environment and the Economy remains active in promoting the principles and practices of sustainable development. It also continues to support important initiatives such as the Forest Round Table on Sustainable Development and the dissemination of information on sustainable communities. In addition, the four remaining provincial round tables continue to hold multistakeholder discussions of environmental concerns. Many major Canadian cities, as well as smaller communities, also have ongoing environmental advisory

Table 16.4

Progress by Canada towards agreed targets for environmental sustainability

Level of action	Issue/accord	Performance by Canada: Goal	Performance by Canada: Level achieved to date
International	Greenhouse gases/Framework Convention on Climate Change (1992)	Stabilize net greenhouse gas emissions at 1990 levels by the year 2000; develop sustainable options to achieve further progress by 2005.	Without new measures, Canada will fall short of goal by 13%. National Action Program on Climate Change developed (1995).
	Ozone-depleting substances/Montreal Protocol (1987)	Elimination of halons (1994), carbon tetrachloride (1995), CFCs, methyl chloroform, and HBFCs (January 1, 1996), methyl bromide (2001), and HCFCs (2030).	All goals met to date; methyl bromide goal accelerated in December 1995.
	SO_2 emissions and acid rain/ Canada–United States Air Quality Agreement (1991)	Reduce SO_2 emissions in seven easternmost provinces to 2.3 million tonnes per year by 1994; permanent national emission cap of 3.2 million tonnes by 2000.	Both goals met ahead of deadline and reductions continuing; eastern emissions of 1.7 million tonnes in 1994 down 56% since 1980.
	Protected areas/Framework Convention on Biological Diversity (1992)	To protect a representative sample of each of the country's natural areas with total amounting to 12% of national territory.	Eight percent of land and freshwater area given some form of protection by 1993, an increase of 15% from 1990. Canadian Biodiversity Strategy developed (1995).
Canada	Nitrogen oxides and volatile organic compounds (1990)/ NOx/VOCs Management Plan	By 2005, no concentrations of ground-level ozone greater than 82 ppb (1-hour period).	Difficult to detect ozone formation trends; ozone exceedances low in 1992–1993, but near average in 1994. Management Plan under review.
	Packaging/National Packaging Protocol	Reduce packaging waste by 20% of 1988 levels by 1992, 35% by 1996, and 50% by 2000 (from 5.3 million tonnes to 2.65 million tonnes).	Interim goal met; 21% reduction of packaging waste by 1992.
	Solid waste	Reduce waste going to landfill and other disposal facilities by 50% of 1988 levels by 2000 on a per capita basis.	Disposal of total solid waste reduced 23.4% per capita, 1988–1992.
	Reduce industrial water effluent/St. Lawrence Action Plan, followed by St. Lawrence Vision 2000	Reduce toxic release from 106 industrial plants along the St. Lawrence.	Toxic effluents by 50 industrial plants reduced 74%; action at another 56 sites.
	PCBs	Destroy all federal PCBs by 1996.	By end of 1993, 30% of PCBs from federal facilities, by weight, destroyed; 50% in storage, and 20% in service in electrical facilities.

Note: Abbreviations used are as follows:

CFCs: chlorofluorocarbons
HBFCs: hydrobromofluorocarbons
HCFCs: hydrochlorofluorocarbons
NOx: nitrogen oxides
PCBs: polychlorinated biphenyls
ppb: parts per billion
SO_2: sulphur dioxide
VOCs: volatile organic compounds

boards or committees and are involved in "healthy communities" initiatives. Bodies and activities like these have had the important effect of changing the expectations of Canadians about their ability to participate in planning decisions and to have their values considered.

Globalisation of economic and environmental linkages

The regional and global nature of many environmental issues, such as climate change, stratospheric ozone depletion, and the long-range transport of atmospheric pollutants, has provided a powerful impetus to international cooperation in the search for solutions to these and other environmental problems. By sharing information and resources, the nations of the world have greatly enhanced their capacity to deal with these issues (Box 16.4). The impetus to conduct environmental and health planning and regulation at an international level, as well as at more local levels, has never been stronger.

At the same time, however, participation in international trade and the globalization of the economy have altered the ability of individual governments to deal with some environmental issues. Not surprisingly, differences in environmental standards have been at issue in international trade agreements such as the North American Free Trade Agreement (NAFTA), although arguably the North American Agreement for Environmental Cooperation allows initiatives for environmental protection not possible before NAFTA. Nevertheless, although international economic and political pressures may inhibit flexibility in some areas, they can also catalyze action in others. For example, the emergence of global standards, such as the Basel Convention regarding the transboundary movements and disposal of hazardous waste and the proposed voluntary ISO 14000 environmental management standards of the International Organization for Standardization, is a response to the need for equity among nations in the bearing of environmental costs. The goal is a level playing field for those who produce for global markets.

To a growing extent, such international standards are the requirement for accessing markets such as the European Community. Therefore, firms are under increased pressure to meet global standards to assure continued access to markets worldwide. As a trading nation, Canada recognizes the importance of such standards and has been providing leadership in the further development of ISO environmental management standards through the Canadian Standards Association (Box 16.5).

Changing government roles

Over the past five years, the government presence in many areas has been reduced, resulting in cutbacks to federal programs dealing with the environment and an increasing devolution of spending and regulatory authority to lower levels.

At the same time, new types of programs are being explored, increasingly in concert with industry and other institutions. A range of instruments, including modification of economic policies, use of financial incentives, joint ventures between governments and nongovernmental organizations, sectoral codes of practice, challenge programs, and public reporting mechanisms (such as corporate state of the environment reports), are all being considered as alternatives to services that have been traditionally provided by government.

Shared responsibility has become a watchword for the environment as agencies seek innovative arrangements to respond to the scarcity of financial resources. As a result, local administrations and private sector organizations as well as partnerships

Box 16.4
The Canadian Global Change Program

The Canadian Global Change Program's mission is to promote informed action through sound advice on global change. Founded in 1985 under the auspices of the Royal Society of Canada, the Canadian Global Change Program is an independent nongovernmental organization that brings together scientists and other specialists from many disciplines to plan interdisciplinary research, assess the significance of this research to policy, and communicate the implications to its target audiences. The Canadian Global Change Program is concerned with both the natural and human dimensions of global change and collaborates with related organizations around the world.

Box 16.5
New international environmental management systems

The International Organization for Standardization's ISO 14000 standards are the first edition of a new series of international environmental management system standards. Scheduled for publication in mid-1996, they are a package of voluntary standards that an organization can use to plan, implement, and monitor measures to improve its environmental performance. The program includes guidelines for:

- *environmental management principles, systems, and supporting techniques;*
- *specifications;*
- *environmental auditing;*
- *labelling;*
- *life cycle assessment; and*
- *inclusion of environmental aspects in product standards.*

In Canada, the Quality Management Institute (a division of the Canadian Standards Association) will register the compliance of a company's environmental management system with the ISO 14000 requirements.

among groups that share common objectives are increasingly dealing with the environment and other matters of public interest. Examples are the trend towards municipal environmental reporting (by such cities as Ottawa), increased reliance on community and voluntary groups such as Ontario Green Communities, and the formation of partnerships among business associations and nongovernmental organizations to promote greater energy efficiency. Clearly, organizations outside government will play a more important role in moving Canada towards sustainability, but it remains to be seen whether these new arrangements can respond more effectively to current and emerging environmental issues.

Resource management

There has been a fundamental change in Canada during the past decade in the ways in which resource management is conceived and practised. The key element of this change has been the recognition that resource development projects must involve affected stakeholders in project planning and implementation. To do otherwise is to risk community opposition or even legal challenges. Many provinces and territories have strengthened their environmental review procedures and provided for extensive public participation. One effect of this development has been a lengthening of the approval process for new projects. Many proponents of development schemes have complained vociferously about delays, and indeed some consultation procedures, such as Ontario's process for landfill sites in the Toronto area, have taken years. There are, however, success stories in which consensus on appropriate solutions has been achieved. Perhaps the best-known recent example is the Clayoquot Sound plan in British Columbia, in which a compromise appears to have been reached on the long-standing issue of the location and extent of lumbering activity in the area. This plan succeeded in integrating values associated with preservation of old-growth forests, wildlife habitat, tourism, Aboriginal culture, and lumbering to the satisfaction of most stakeholders.

Some examples of initiatives that have promoted sustainable resource management over the past five years are increasing use of comanagement practices in northern communities, the Model Forest Program, the National Forest Accord, the National Agriculture Environment Committee, the environmental code of practice of the Canadian Pork Council, and a number of programs to reduce the environmental impacts of mining (e.g., the Assessment of the Aquatic Effects of Mining in Canada process and the MEND program). (For additional details, see Chapter 11.) These programs help to further research into the effects of resource management practices, facilitate multiple use of resources, create partnerships to address key issues, and generate useful demonstration projects to aid each sector in its efforts to redress past problems and implement sustainable management practices. Additional examples of sustainable resource management initiatives were noted above.

Conservation: living within our means

Over the past five years, the growing demand on Canada's resources has encouraged a better recognition of the need to manage resources, species, and ecosystems effectively. The collapse of the Northern Cod stocks, in particular, provided concrete evidence that overharvesting of species and ecosystems can result in disastrous consequences. Consequently, natural resource management strategies are giving greater emphasis to conservation efforts such as the Atlantic Groundfish Strategy and broader initiatives such as the Oceans Management Strategy. Effective conservation based on sound knowledge, effective monitoring, and stringent enforcement where necessary should mean that drastic measures, such as the closure of the commercial cod fishery, can be avoided. The objective is to seek sustainable solutions that are both economically and environmentally sound.

A greater awareness of the need for more effective conservation is reflected in a number of recent initiatives. These include fuller-cost urban water pricing based on volume consumed, the Permanent Cover Program, which returns marginal cropland to pasture, and landowner stewardship in support of wildlife habitat by such organizations as Ducks Unlimited, the Nature Conservancy of Canada, and Wildlife Habitat Canada. To help address freshwater challenges, Environment Canada is currently leading in the development of a federal freshwater strategy. For the Arctic, Canada and seven other circumpolar countries adopted the Arctic Environmental Protection Strategy in 1991. The strategy commits the eight countries to cooperate on protection of the Arctic environment and to support its sustainable and equitable development. While these latter changes are primarily institutional, they provide the basis for a more knowledgeable consideration of environmental values and should lead to better decisions regarding the use and management of natural resources.

The conservation of rural ecosystems has also advanced through a number of local conservation initiatives and through continent-wide programs such as the NAWMP. This program has served to funnel millions of dollars from those who benefit from hunting in Canada and the United States to the farmers who maintain the habitat used by ducks. The NAWMP continues to provide assistance to farmers for the development of conservation plans that enhance the diversity of agricultural landscapes and integrate production, habitat, water management, and erosion control objectives. Further voluntary environmental farm initiatives are being advanced by farm groups in several provinces.

Approaches to conservation are also being shaped by the increasing realization that government agricultural programs can have unintended environmental consequences. In the past, many programs encouraged increased production without full consideration of environmental side effects — for example, by subsidizing the removal of natural areas, drainage of wetlands, and cultivation of slopes. More recently, however, the renovation of agricultural support programs and transportation subsidies has removed some of the incentives for farmers to undertake grain monoculture on marginally productive

land, thus encouraging the reestablishment of natural cover in these areas. As a result, the potential for soil degradation has been reduced, and a trend towards restoration of biological diversity to agricultural landscapes has been established.

As a signatory to the 1992 Framework Convention on Biological Diversity, Canada responded in 1995 with the Canadian Biodiversity Strategy. The strategy provides a framework for action at all levels that will help support the productivity and diversity of natural systems. The strategy is also supported by such initiatives as BIOMAP, a federal multidepartmental process that assists in identifying and cataloguing important elements of biodiversity. In addition, the goal of designating 12% of its territory as protected area remains a key component of Canada's Biodiversity Strategy (see Table 16.4).

Reducing waste

Higher tipping fees that correspond more closely to the actual costs of maintaining landfills are providing a disincentive to waste disposal and therefore contributing to waste reduction and recycling and the development of markets for recycled material. Over the past five years, there has been significant progress in home composting, recycling (mainly of glass, metals, and plastics) through blue box programs, and waste reduction in large businesses, although Canadians are still among the world's leading producers of domestic waste.

At the national level, the National Packaging Protocol and National Solid Waste Management Program of the Canadian Council of Ministers of the Environment have been an important stimulus to waste reduction by industry, governments, and households. The National Solid Waste Management Program has the objective of reducing Canada's annual per capita output of solid waste to 50% of the 1988 level by the year 2000. As of 1992, total disposal of solid waste (municipal, construction, and demolition) in Canada had decreased by 23.4% per capita from the 1988 baseline year. The National Packaging Protocol has set a similar target for the reduction of waste packaging (i.e., a 50% reduction from the 1988 level by the year 2000). This would reduce the total amount of packaging used from 5.3 million tonnes to 2.65 million tonnes. The protocol was successful in reaching its interim target of a 20% reduction by 1992 (see Table 16.4).

Some of the most innovative waste management programs have come from the private sector. Through its Pollution Prevention Pays program, the 3M Corporation reduced waste disposal volumes at an Ontario manufacturing plant from 2 800 to 115 t per year, with annual savings of $1 million (Environment Canada and Industry Canada 1994). Models such as this demonstrate that better waste management not only can reduce risks and potential liabilities but in some cases can also bring economic benefits to the firms that implement it.

Hazardous wastes are a direct threat to ecosystem health and require special treatment and disposal to render them harmless or, at least, less dangerous (Box 16.6). In 1990, 4 of the top 10 generators of hazardous waste in Canada were manufacturing industries. There are indications, however, that these industries are taking their responsibilities with regard to hazardous waste management more seriously. One of the more noteworthy voluntary initiatives is the Improving Manufacturing Environmental Performance Program of the Canadian Manufacturers Association, which has been designed to improve environmental performance in small and medium-sized manufacturing operations.

Canadian households also generate sizeable quantities of hazardous materials. Over the past decade, many cities have established periodic or permanent hazardous waste depots to ensure the safe disposal or recycling of these materials. Between 1991 and 1994, the proportion of households with access to such facilities rose from 26% to 40% (Statistics Canada 1995). Some municipalities also distribute brochures to encourage less use of consumer goods that contain toxic materials.

Making Canadian cities and urban transportation more sustainable

Urban centres account for less than 20 000 km^2, or about 0.2%, of the nation's land area. In this area live 75% of Canada's people, with nearly 60% of these residing in cities of 500 000 or more individuals. These urban centres are the hub of a supply system that provides residents with food, clothing, housing, recreation, and all of the attractions that have spurred a continuing migration to these localities. Food, fibre, minerals, water, and energy flow into the cities from surrounding ecosystems; flowing out are wastewater, garbage, air contaminants, and urban residents seeking nature and recreation. Cities are conse-

Box 16.6
The Alberta Special Waste Treatment Centre in Swan Hills

The Alberta Special Waste Treatment Centre, North America's first integrated hazardous waste treatment facility, was opened in 1987. It is permitted to treat all types of wastes, with the exception of radioactive and explosive materials and biomedical wastes. Accepted materials fall into five major categories:

- *inorganic wastes;*
- *organic wastes;*
- *metal-bearing wastes;*
- *household and laboratory wastes; and*
- *transformers.*

Wastes are burned or chemically treated to make them relatively innocuous. Residues are buried in secure landfills or injected deep underground. Since 1995, the Government of Alberta has allowed the importation of hazardous wastes from other provinces for treatment at the site.

quently the source of many environmental stresses, but they can also be a catalyst for solutions.

Population density is sometimes an asset in solving environmental problems. It is much easier, for example, to provide clean water and effective sewage treatment systems for concentrated populations than for dispersed populations. Similarly, it is easier to run recycling programs in larger centres, because large amounts of waste materials (e.g., glass, aluminum cans, paper, and plastics) can be collected more efficiently from a small, densely populated area. As well, the large urban population can draw on many more people to provide leadership for such initiatives. As a result, Canada's municipalities have often led the way in implementing innovative programs to promote environmental sustainability (see Chapter 12).

However, results of attempts to improve the sustainability of urban environments are mixed. On the positive side, there is an emerging trend towards smaller, more energy-efficient homes and more home-based businesses. One can also point to the increased prevalence of green community planning processes, tighter land use controls, intensification policies (infill and redevelopment of land at higher densities), and a growing adoption of mixed land uses (see Chapter 12). In spite of decreasing government resources, greater importance is also being attached to protecting ecologically significant areas in urban landscapes. On the negative side, many Canadians continue to prefer single-family detached dwellings in low-density neighbourhoods, and many new businesses are established in low-density business parks. The result is continuing reliance on the automobile and, therefore, on the transportation infrastructure that supports the automobile at the expense of public transportation.

In most cities, the sluggish economy of the past several years has reduced support for new public transit systems, thus furthering the dependence of Canadians on the automobile. However, many municipalities have also tried to find ways of increasing the use of public transit services. Some cities have experimented with higher parking fees to try to make public transport relatively cheaper than the use of private vehicles, but the results have not been promising. The development of preferential lanes for buses and car pools has had limited impact on the single-occupant car commuter — who, at this point, is still the average Canadian. Indeed, an array of municipal initiatives has been directed towards sustainable transportation, although many of these are still at the planning or testing stage (see Fig. 11.51, Chapter 11). In spite of these efforts, the number of cars and the extent of their use continue to rise. The impact of greater car usage has been offset to some extent, however, by a reduction in the amount of raw material used in vehicle production and by continuing reductions in average fuel consumption and emissions, although these have been less dramatic since the 1980s.

Transportation is essential to Canada's economic and social fabric, yet current transportation practices seem to be environmentally unsustainable from two primary perspectives: pollution and fuel supply. Recognition of the importance of environmentally sustainable transportation has spurred such international agreements as the Nitrogen Oxide Protocol, the Volatile Organic Compounds Protocol, and the Canada–United States Air Quality Agreement. At the local level, it has inspired such initiatives as the Air Care Program in British Columbia's Lower Mainland and the municipal "Twenty Percent Club," in which eight of Canada's largest urban centres have made commitments to reduce their greenhouse gas emissions by 20% from 1988 levels by the year 2005 (see Chapters 11 and 12). However, these actions may not be sufficient to reverse long-standing trends towards increasing transportation activity. In addition, it is likely that technological innovations (e.g., increased fuel efficiency, alternative fuels, electric vehicles, and the use of lighter materials in vehicles) will have only a limited effect on fuel use and emissions in the short term, although research in these areas is continuing under federal and international climate change initiatives. In the summer of 1995, the federal Minister of the Environment announced that new regulations would be developed under CEPA to limit the benzene content of gasoline to 1% by volume. The regulations will also limit any increase in the amount of benzene compounds. This move is expected to reduce emissions of benzene from vehicles by about 20%.

Controlling pollution

Despite the economic uncertainties of the past five years, the Canadian public continues to place a clean and healthy environment high on its list of priorities and expects public and private institutions to do likewise. More meaningful fines for pollution offences (such as a recent $160 000 fine for illegal operation of a waste transfer station in Ontario) may have been a factor in the reduction of many pollutants identified as priority concerns in the last *State of Canada's environment* report (Government of Canada 1991). Compliance surveys also suggest that concerns over personal and corporate environmental liability, demands from insurance and lending institutions, and corporate image considerations are key factors in pollution reduction.

As a first step towards meeting its obligations under the United Nations Framework Convention on Climate Change, Canada, along with most other developed countries, is aiming to stabilize its net greenhouse gas emissions at 1990 levels by the year 2000 (see Table 16.4). To move towards this target, Canada's National Action Program on Climate Change (Canadian Council of Ministers of the Environment 1995) contains a range of largely voluntary and sector-specific measures. Program options (see Chapter 15) include:

- the development of incentives, regulations, and technical training to improve energy efficiency in the residential and commercial sectors;
- the alteration of subsidies in the energy, transportation, agriculture, and forest industries to discourage activities that

increase greenhouse gas concentrations and encourage those that do not; and

- measures to encourage the use of more fuel-efficient cars.

Under the federal Efficiency and Alternative Energy Program, 37 initiatives are under way to improve energy efficiency and improve the use of alternative energy in Canada.

In spite of these programs, stabilizing Canada's energy-related greenhouse gas emissions at 1990 levels will be a difficult task. Whether present, largely voluntary, measures under the National Action Program are sufficient to achieve this goal by the year 2000 (and to forestall a forecast 13% increase in energy-related emissions over 1990 levels based on current energy consumption trends; Canadian Council of Ministers of the Environment 1995) is an open question. The program's first progress review, due in 1996, should provide a clearer picture of whether these measures are proving effective and whether further action is needed (see Chapter 15).

Canada has made good progress in its program to reduce acidic deposition and has surpassed its emission reduction target for sulphur dioxide. By 1994, sulphur dioxide emissions in the seven easternmost provinces were down to 1.7 million tonnes, 56% below the 1980 level (see Table 16.4). Canada is also in the process of developing a National Strategy on Acidifying Emissions for beyond the year 2000. This strategy will aim to protect acid-sensitive areas, human health, and air clarity in Canada. The strategy is expected to be completed by early 1997 and will come into effect when the Canadian Acid Rain Control Program expires in 2000.

With respect to local air pollution, the national NOx/VOC Management Plan is currently under review. Progress to date is being assessed, and the next steps to resolve the ground-level ozone problem are being discussed. In addition, the Federal–Provincial Advisory Committee on Air Quality is reviewing current air pollution objectives.

In November 1991, a $10 million Ocean Dumping Control Action Plan was initiated to strengthen regulations, enhance surveillance, and set up a national program to reduce persistent plastics in the marine environment. Increased monitoring of disposal sites has been achieved, and improved monitoring guidelines are being tested and implemented (see Chapter 10). This effort augments Canada's regulation of disposal at sea by permit under CEPA and the Ocean Disposal Regulations in order to comply with the London Convention (1972).

To determine which substances pose a toxic risk, the federal government established a Priority Substances List under CEPA in 1989. Assessment of the 44 substances (or groups of substances) on the list was completed in 1994. A second list, identifying 25 substances that will be given priority for scientific assessment, was published in December 1995. A National Pollutant Release Inventory has also been established. Although this progress is encouraging, it is only part of the much larger overall task of identifying, monitoring, and controlling toxic substances in the environment.

One of the major problems in determining the safety of chemical products is the sheer number already in existence. The European Inventory of Existing Commercial Chemical Substances, for example, lists 110 000 chemicals, and about 1 000 new substances are becoming available every year. The New Substances Notification Regulation under CEPA requires manufacturers and importers to supply toxicological and other specified information on new commercial substances introduced into Canada. Clearly, knowledge of these newly added substances is of great importance, as it will form the basis for action and regulation directed at their control.

One of the more prominent industrial responses to pollution has been the Responsible Care® program of the Canadian Chemical Producers' Association. This program guides the management of chemicals from "cradle to grave" (i.e., from research and development to use and disposal). Under the program, member companies report emissions of chemical substances to air, water, and land and make emission reduction projections (Canadian Chemical Producers' Association 1994). In 1993, the Canadian Chemical Producers' Association released a list of 306 chemical substances that it considered significant from a human health or environmental perspective: all of these come under the "cradle to grave" management guidelines of the association's Responsible Care® program. In addition, 178 of these substances are listed in Environment Canada's National Pollutant Release Inventory, and 78 more are slated for action under the voluntary Accelerated Reduction/Elimination of Toxics (ARET) program. The Canadian Chemical Producers' Association (1994) projects a 72% reduction in total emissions of its 306 listed substances by 1999 compared with 1992 emission levels (see Chapter 11).

Approaches to the management of toxic substances are evolving rapidly. Sophisticated full-system approaches to industrial processes are replacing simple "end-of-pipe" techniques. Life cycle analyses are being used more commonly, and a new "industrial ecology," which approaches the management of industrial impacts from a more holistic perspective, is emerging (see Chapters 11 and 13). Rigorous systems of site assessment and environmental auditing are also becoming commonplace. An overall pollution prevention strategy incorporating these ideas is now a central theme in federal government policy (Government of Canada 1995b).

Such policies and programs as the Toxic Substances Management Policy (Government of Canada and Environment Canada 1995) and the National Pollutant Release Inventory are making it easier to track releases of pollutants into the environment. The results can help identify pollution sources and promote more effective management of polluting processes as well as their eventual conversion to more sustainable alternatives. The Toxic Substances Management Policy establishes a precautionary, proactive, science-based management framework that will be applied in all areas of federal responsibility. One of its key management objectives

is the virtual elimination from the environment of toxic substances that result from human activity and that are persistent and bioaccumulative (see Chapter 13).

Lurking legacies: paying off past environmental debts

The state of Canada's environment — 1991 reported that there were an estimated 10 000 sites in Canada in 1989 that were potentially contaminated with environmentally harmful substances (Government of Canada 1991). These sites include former industrial facilities, railyards, closed metal mines, waste disposal areas, former gasoline stations, fuel storage areas, and harbour bottoms. Many of these are orphan sites, for which no responsible party can be found that is capable of paying for remediation. Remediation of the remaining sites, and others, remains a matter for the governments and landowners responsible for them to complete. According to the Federal Facilities Environmental Database, the federal government has direct responsibility for at least 1 200 potentially contaminated sites.

Often the magnitude of the environmental debt overwhelms the potential value of the site. The cost of cleaning up leaking underground storage tanks has averaged about $150 000 in Canada, with some sites costing millions of dollars, particularly where contamination affects aquifers. Although hundreds of sites across Canada have been remediated, most older gas stations (of which there are thousands) likely lie atop tonnes of contaminated soil. Normally, this soil must be cleaned or removed if the site is to be sold or used for other purposes. Nearly all former heavy industrial sites have areas contaminated by hydrocarbons, heavy metals, or waste materials produced through decades of "normal" industrial activity. Former military bases and Distant Early Warning (DEW) Line sites are known to be contaminated with a variety of wastes, including waste oils, aviation and diesel fuels, PCB-containing transformers and capacitors, solvents, CFCs, and lindane.

With stronger laws regarding contamination and rising civil settlements for damages, owners of properties with current and past environmental liabilities often face immense potential costs. Increasingly, industry is making use of environmental auditing to identify these liabilities. This evolving practice allows remedial or preventive action before civil damages or noncompliance with regulations results in high costs to the organization. Similarly, governments are moving, often through remedial action plans, to clean up areas where the risk is the greatest (as in the 16 remaining "Areas of Concern" on the Canadian side of the Great Lakes).

As environmental cleanup activities become more common, new, more affordable remediation technologies are emerging. Particularly promising are in situ techniques using bacteria normally present on each contaminated site (some of which have adapted to the presence of the contaminants and are able to use them as a carbon source). Unfortunately, cleaning up chemicals that have entered the subsurface has turned out to be a complex matter, and solutions are rarely simple or inexpensive.

Site remediation

Some 325 federal sites, along with 48 orphan sites, were recently assessed under the National Contaminated Sites Remediation Program, a federal–provincial initiative to identify, prioritize, and manage particularly worrisome contaminated areas. By 1995, remediation had been started on 18 of the federal sites, but the program was terminated in March 1996, and it is unclear if work will continue. Eleven orphan sites were cleaned up under the program, and a further eight or nine were to be completed by 1996. The program, which began in 1991, also sponsored 45 projects for the development of new remediation technologies.

A federal program to clean up sites contaminated by leaking underground storage tanks and remediate abandoned mines may also cease because of the current need to cut costs. However, termination of this and similar programs may increase costs in the long run, as persistent toxic substances tend to migrate over time, thus increasing the contaminated area. To some extent, responsibility for cleanup of contaminated sites is being devolved to lower levels of government, and a variety of local and provincial initiatives to develop inventories of toxic sites and deal with the most hazardous locations are now in progress.

A number of sites across Canada have been contaminated with low-level radioactive waste as a result of past practices that are no longer permitted. In cases in which no responsible owner has been found, the federal government has assumed responsibility for the cleanup, and it has remediated low-level radioactive waste sites in a number of communities. In 1995, the federal Siting Task Force on Low-Level Radioactive Waste Management carried out a consultative process to identify a community willing to host a low-level radioactive waste disposal facility. Deep River, Ontario, was selected, and the government is studying the Task Force's recommendation.

Many of the remaining problems reflect the limits of current technology and knowledge. After several decades of effort, the Sydney Tar Ponds remain contaminated, and there is controversy over new proposals to seal and monitor the site while leaving the contaminants in place. Similar controversy surrounds other waste sites, where the costs of remediation are very high and no source of funds is evident. Proposals to seal such sites and monitor them for off-site migration of the contaminants are becoming increasingly common. While sealing in contaminants may significantly reduce the short-term risk to surrounding communities, the procedure remains controversial and often fails to meet the demands of neighbouring communities. This stop-gap measure also has the effect of postponing responsibility for cleanup and transferring it to future generations.

Changing decision-making

There is an increasing awareness of the need to improve decision-making processes that deal with the management of natural resources and ecosystems, if the goals of the World Conservation Strategy are to be realized. The 1987 Brundtland Com-

mission and the 1992 Earth Summit both pointed out that decision-making processes based on greater integration of environmental and economic considerations are critical to sustainable development. In Canada, the move to more environmentally sensitive decision-making may already be under way. Recent instances of successful ecosystem-based planning and community-based action include the Crombie Commission in Toronto, Hamilton's Vision 2020, and the Task Force on Healthy and Sustainable Communities of the University of British Columbia and the City of Richmond, B.C. The initiatives summarized in Table 16.3 indicate areas in which environmental concerns have been integrated into decision-making. A real, if subtle, result of the Earth Summit in general, and *Agenda 21* in particular, has been the recognition that changes in consumption patterns, resource planning, and wealth distribution will be necessary over the coming decades. Although Canada and other countries are already documenting their activities in response to *Agenda 21* through annual reports to the United Nations Commission on Sustainable Development, it remains to be seen whether they can respond to all of the Agenda's expectations. Whether these changes will be made with foresight and deliberation or in rapid reaction to sudden crises and emergencies is also unknown.

One of the most important developments in the past five years has been the approval of legislation to establish a new Office of the Commissioner of the Environment and Sustainable Development. This agency will be located within the Office of the Auditor General and will report to Parliament. The Commissioner will be charged with overseeing the federal government's performance in achieving sustainable development, and all federal ministers will be required to integrate sustainable development into their policies and programs and be held accountable to Parliament. Internationally, the Commission for Environmental Cooperation, organized under NAFTA, has been established. The commission, with headquarters in Montreal, is charged with facilitating cooperation on environmental matters between Canada, the United States, and Mexico.

Despite some reductions, national and provincial round tables and, particularly, local community-initiated programs have emerged as an important element in delivering the sustainable development agenda (Box 16.7). As well, voluntary initiatives by private industry, such as codes of practice (in the petroleum, tourism, and agriculture sectors, for example), and participation in regional remedial action plans are increasingly important. These are strong signs of the internalization of environmental ethics into communities and the business world.

Business organizations have also begun to use the principles of risk management to help control their exposure to threats of all sorts, including environmental problems. Increasingly, the "detect and react" approach to managing problems is giving way to an "anticipate and prevent" strategy.

Public consultation on the design and implementation of decision-making strategies is becoming more accepted as normal practice. In addition, the development of better ways of disseminating information (such as Environment Canada's Green Lane on the Internet) is helping to keep the public and decision-makers in specific sectors better informed. Public consultation figured prominently in the design of the National Forest Strategy. Similarly, the national consultations that led to the formulation of Canada's position at UNCED, one of the most comprehensive multistakeholder consultation processes ever undertaken in this country, allowed thousands of Canadians to voice their concerns over environmental issues.

Multistakeholder consultation is also playing a part in the follow-up to the Earth Summit and the parallel 1992 Global Forum (which was attended by 18 000 people from 166 countries). To maintain the momentum created by these events, Canada established the "Projet de société," a national partnership representing government, Indigenous peoples, business, and nonprofit organizations. Intended to establish a process through which Canada can implement its commitments to UNCED, it has provided a forum for building consensus on appropriate actions linked to the common purpose of sustainable development. Through the Projet de société, work towards a national sustainable development strategy was undertaken and partially fulfilled with the publication of *Canadian choices for transitions to sustainability* (Projet de société — Planning for a sustainable future 1995). Although it faces serious financial constraints, the Projet de société is still actively seeking innovative ways to share knowledge and resources.

Box 16.7
The National Round Table on the Environment and the Economy

The National Round Table on the Environment and the Economy was created in 1988 as one of Canada's principal institutional responses to the challenges of sustainable development. Its role is to generate awareness of environment–economy issues by identifying, explaining, and promoting the principles of sustainability to government, business, and the broader community. Membership consists of a chairperson and 24 distinguished Canadians, all appointed by the Prime Minister.

The National Round Table on the Environment and the Economy helps government address public policy questions relating to sustainable development, furnishes a neutral meeting ground where stakeholders can work together to tackle natural resource and environmental issues, and produces a broad range of information and publications to encourage grassroots initiatives. The proclamation of the Round Table Act *in 1994 confirmed the status of the National Round Table on the Environment and the Economy as a key forum for the discussion of sustainability issues.*

The public forum process has also been used in reviews of federal policy instruments (e.g., CEPA and the *Canadian Environmental Assessment Act*) and in provincial policy reviews (e.g., the Sewell Commission's review of Ontario's *Planning Act* and the development of the Forest Practices Code by the Province of British Columbia) (Box 16.8). Industry organizations, like the Canadian Manufacturers Association and the Canadian Chemical Producers' Association, have begun to use participatory processes in the development of their environmental programs as well.

Education is a major influence on how Canadians understand and react to environmental issues and is key to making sustainable development a reality. The use of educational materials, including state of the environment reports, for example, helps ensure that future decision-makers will be better informed than their predecessors about the potential consequences of their actions. A positive step in this respect has been the greater integration of environmental modules into school curricula in most provinces.

Many provinces, municipalities, corporations, round tables, and other organizations are now producing their own state of the environment reports, and most annual reports of large companies also have an environmental section. Whereas some reports are comprehensive (e.g., those of Inco, MacMillan Bloedel, Ontario Hydro, most oil companies, and most chemical companies), others are more limited, focusing on either the listing of outstanding environmental liabilities (such as contaminated sites) or specific achievements in such areas as waste reduction or paper recycling. Nevertheless, these reports provide evidence that the boardrooms of the nation are aware of the growing need to incorporate environmental issues into their planning.

An emerging decision-making tool for managers charged with environmental responsibilities is the use of indicators of sustainability. Environmental indicators are important tools for translating and delivering concise, scientifically credible information in a manner that can be readily understood and used by decision-makers at all levels of society. Environment Canada's State of the Environment Directorate (Indicators Branch) is charged with developing a comprehensive national set of environmental indicators that gives a representative profile of the state of the environment and helps measure progress towards the goals of sustainable development. Canada has also been a leading participant in international efforts to develop better environmental indicators through such international bodies as the OECD and the United Nations Environment Programme (UNEP). More is said about the development and use of environmental indicators in the following section.

With the downsizing of government and the removal of many economic subsidies, market-based instruments have become more important as a means for influencing behaviour and meeting environmental objectives. Some of these were discussed in the last *State of Canada's environment* report (Government of Canada 1991), and several recent developments have already been referred to in this chapter. Water pricing by volume, for example, has clearly resulted in reduced water use in some municipalities. More realistic tipping charges have also caused many municipalities and firms to pursue recycling measures and reduce the amount of waste sent to disposal. Deposit refund systems for products like bottles and other types of containers are proving very effective. In addition, quota systems and licensing continue to be used to reduce impacts from commercial fishing, sport fishing, and hunting, but they have not been extended to other economic sectors.

Progress in the use of broader economic instruments, such as pollutant emission charges, however, has been much slower. Although discussion continues about the use of these instruments, governments have, for the most part, hesitated to put them into effect. For example, the application of "green" taxes or environmental charges have, for the most part, been limited to paying for the environmentally safe disposal of a few selected products.

Box 16.8
The Canadian Environmental Assessment Agency

Environmental assessment has been practised by the Canadian government since 1974 to predict the potential environmental effects of proposals involving federal interests. The environmental assessment process was updated in 1977 and reinforced in 1984 when the Environmental Assessment and Review Process Guidelines were issued by Order-in-Council. In 1992, the guidelines were superseded by the Canadian Environmental Assessment Act. *At the same time, the Federal Environmental Assessment and Review Office became the Canadian Environmental Assessment Agency. The cornerstones of the act are four regulations known as the Exclusion List, Inclusion List, Comprehensive Study List, and Law List. The Exclusion List identifies projects that are excluded from environmental assessment procedures (i.e., those without significant impacts). The Inclusion List contains activities that require environmental assessment as a matter of course because they have a high likelihood of significant impacts. The Comprehensive Study List covers projects for which significant impacts are probable and detailed study is needed. Finally, the Law List covers provisions of other acts that may have an environmental impact and must therefore go through the assessment process.*

Activities during the Canadian Environmental Assessment Agency's first year of operation included the assessment of impacts related to programs and policies, transboundary issues, the shifting of powers to the provinces, and Native self-government, as well as the examination of general perceptions about environmental assessment.

Despite reductions in government spending and the termination of some programs begun in the 1980s, most environmental initiatives remain in place, although often in modified or reduced form. The integration of environmental values into government, institutional, and private decision-making processes is continuing, but there is nevertheless a growing concern that environmental programs may be further reduced as a result of government fiscal constraints.

Taking the Pulse of the Environment

In the past, Canada had one of the most progressive and extensive systems of natural resource and environmental data in the world. The product of a variety of programs, this information provided the foundation of an understanding of the limits and opportunities associated with natural capital. These programs included both sectoral surveys (e.g., of water resources, soils, and geological characteristics) and unique integrated data sets and programs (e.g., the Canada Land Inventory and the Northern Land Use Information series). It is ironic, therefore, that at a time when data requirements are growing and the ability to analyze, integrate, and communicate environmental information is better than ever before, many of these programs, particularly those for compiling integrated data sets, no longer exist.

In the five years since the last *State of Canada's environment* report (Government of Canada 1991) was published, there has been mixed success in collecting data to measure impacts on the environment and the effectiveness of mitigation efforts. In preparing the present report, the contributors had difficulty obtaining information, especially time series data, on many important topics. Very little of this information has been integrated in an ecosystem context, with the exception of the material that has been compiled within the ecozone/ecoregion frameworks (Wiken 1986; Ecological Stratification Working Group 1996). A few long-term programs that have been useful in identifying trends in important areas such as urban air quality have continued to collect useful information. Some new programs such as the National Pollutant Release Inventory are providing systematically gathered and quality controlled data in areas where none existed before.

Table 16.5 summarizes the state of key environmental data in Canada. While the ability to measure changes in several critical variables (such as concentrations of toxic substances, water quality, and regeneration of forests) has been augmented, the preparation of the present report has also revealed important and continuing gaps in the data needed to identify and evaluate many significant environmental relationships and changes. Many important stresses on ecosystems, such as the urbanization of farmland, are not systematically measured at the national level on a regular basis, nor are many impacts, such as the presence of residual toxic substances in many species. Often the results of one-time studies that may provide reasons for concern about particular issues (such as the presence of toxic substances in game food in the North) have been used as the basis for more far-reaching conclusions. Moreover, many national data sets have been derived (with some difficulty) from various other data sources that were compiled by different jurisdictions or industry sources with little standardization in definition or methodology. These problems were identified in the last *State of Canada's environment* report (Government of Canada 1991), and, while there has been limited progress in certain areas (such as the compilation of a toxic substances inventory under CEPA and the accumulation of information on packaging waste), most of the data gaps remain unfilled.

Overall, Canada's environmental monitoring networks are focused on southern Canada, concentrate largely on air and water measurements, have relatively few long-term records, and target mainly individual environmental components rather than ecosystems as a whole (Wiken 1994). Although some integrated monitoring activities are under way, including the Acid Rain National Early Warning System and the network of ecological science cooperatives (see Box 5.12, Chapter 5), Canada remains far from having a long-term environmental monitoring and assessment capability for comprehensively studying resources at risk, ecosystem responses, and the impact of major disruptions to the ecosystem.

In the context of integrated ecosystem planning and development of sustainability measures, data are frequently fragmented, anecdotal, and sparse. There is not, for example, a consolidated database that can provide ready information on national or provincial initiatives for integrating or streamlining cross-sectoral resource management concerns. Even with improved monitoring systems and increased use of mechanized and remote sensing, data collection programs have failed to provide the comprehensive and integrated data needed to assess progress towards sustainability. Moreover, in the face of reduced government expenditures, some of these programs are increasingly vulnerable to being phased out, and, if they disappear, some of the national baseline data and the ecosystem-specific monitoring that they provided may cease altogether.

At the same time, greater requirements for environmental assessments of specific sites and environmental reviews of projects, programs, and policy initiatives are increasing the need for data. There is, consequently, a growing tendency towards ad hoc data collection by firms, municipalities, other governmental bodies, and nongovernmental organizations to suit specific needs, with little consideration for the use and integration of the data for other purposes (such as the establishment of new databases). Moreover, data collected for environmental auditing purposes may be confidential and therefore inaccessible to the public or even to regulatory agencies.

Environmental indicators are selected key statistics that represent or summarize a significant aspect of the state of the environment, the sustainability of natural resources, and the status of related human activities. Indicators for 16 environmental issues have been under development by Environment Canada's National Environ-

Table 16.5

Data availability for state of the environment reporting

Component or activity	Data availability	
	Strengths	Gaps
Ecozone • Ecosystem information and integrated monitoring	• Comprehensive, up-to-date terrestrial classification system of 15 ecozones, 217 ecoregions, and 1 020 ecodistricts; some initial work on marine ecozones • Work towards integrated monitoring: Ecological Science Cooperatives	• Environmental monitoring focuses on mainly southern Canada; largely limited to physical components; few long-term records • Few ecosystem-level measures
Atmosphere	• National Air Pollution Surveillance Network of 55 localities for TSP, SO_2, NO_2, O_3, CO • Monitoring of selected air toxics (e.g., benzene) has begun • Estimates of CO_2 emissions and levels, CFC production • Measurements of very small particles (PM_{10}) at some stations	• Relatively few air toxics monitored on a national basis • No long-term records for air toxics • Fine particles: monitoring just starting • Comparative lack of data on many variables in rural and remote regions such as the Arctic and Taiga ecozones
Fresh water	• National network to measure water quantity information (streamflow) • National survey of 1 500 municipalities: water use, water and wastewater treatment, water shortages, and water pricing since 1983 • Survey of industrial water use • Water quality measures in selected areas • Acidic deposition in lakes monitored selectively	• Groundwater use and contamination • No national system to measure water quality • No national data on beach closures • Only selected contaminants monitored on a site-specific basis
Oceans	• Up-to-date classification of marine ecozones developed • Shellfish bed closures/openings • Commercial fish catches and level of fishing effort • Contaminants in seabird eggs • Industrial and municipal effluent to coastal waters • Regulatory data for ocean dumping sites	• Overall measures of ocean ecosystems and relationships • Measures of biomass; estimates of fish productivity • Ocean temperatures, few stations to record
Land	• Agriculture report, *Health of our soils*: soil quality and crop productivity data (1995) • Risk potential data (wind and water erosion, salinization) for selected regions; soil degradation risk indicator under development • Geological and soil data for settled Canada (some need updating) • Canada Land Inventory, land capability for agriculture, forestry, recreation, and wildlife in the settled portion of Canada (circa 1965–1975) available • Northern Land Use Information mapping (circa 1970–1983) available	• Integrated land data series (i.e., Canada Land Inventory, Northern Land Use Information) not updated • No nationally consistent, comprehensive land use, land use change, urban land use data collected on a regular basis • Data on land use change around major cities available 1966–1986, only partially updated 1986–1991
Wildlife, biodiversity	• Data for species of recreational or economic importance (numbers, range, and habitat) • For species known to be at risk (endangered, threatened, and vulnerable), there is a comprehensive status report. Approximately 50 new reports completed (1991–1996) • National survey of value of wildlife to Canadians (five-year intervals) • Migratory birds, waterfowl data • Wetlands inventory and classification	• Trend data on most species not widely available • Few or no data on lower plants, invertebrates, or microorganisms

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Table 16.5 (continued)

Data availability for state of the environment reporting

Component or activity	Data availability: Strengths	Data availability: Gaps
Protected areas: outdoor recreation and tourism	• National Conservation Areas database (IUCN categories I–VI) • Inventory of internationally protected areas • Inventory of NAWMP enhanced, protected, and influenced areas • Socioeconomic information for national and provincial/territorial parks: visitations and use • Periodic surveys of outdoor recreation (e.g., sport fishing)	• National comprehensive trend data on ecosystem quality in protected areas not fully developed in an integrated way • Incomplete data on areas partially protected by zoning, recreation areas, or hunting regulations • Only selected site-specific data on environmental effects of major recreational resorts and activities
Agriculture	• National and local trend data on farms, extent and use of farmland, crops grown, livestock, inputs such as management machinery, fertilizers, pesticides, and practices such as summerfallow, drainage, and irrigation • *Health of our soils*: soil quality and productivity data (1995) • Soil risk data (wind and water erosion, salinization, etc.) • Agricultural land capability data (circa 1965–1975) • Site-specific studies on environmental effects of agricultural practices • Agricultural–environmental indicators under development	• Canada Land Inventory agricultural land capability data out of date • Nationwide agricultural land loss data around urban centres generally not available since 1986 • Data on agricultural impact of acidification, ground-level ozone, climate change incomplete • Data on extent and impact of farm conservation practices incomplete
Forestry	• Annual *State of forests in Canada* report • National framework of six criteria and 83 indicators of sustainable forest management endorsed; first status report in 1996 • Data nationwide by ecozone/ecoregion on forest area, forest type (species, age, class, etc.), area cut, area regenerated, area lost or damaged by fires and pests • Forestry sector economic, employment, and trade data • Recent trend data on dioxins, furans, and other toxics for pulp and paper sector	• Inconsistency in definition, terminology, administrative boundaries, and time period collected between provinces makes comparison of forestry trends difficult • Lack of data and in-depth analysis on implications of cutting old growth and regeneration • Lack of information for areas outside commercial forests
Fisheries	• Trend data on fish catches, fishing effort • Fish abundance survey data for many species • Models, estimates of fish stock • Shellfish bed closures and openings in most regions • Marine ecozone typology developed	• Relationship between fish stock abundance and environmental factors imperfectly known • Toxicity levels in fish available only for selected species and locations • Much to learn about functioning of marine ecosystem, its effect on the food chain and commercial species
Energy production and use	• National energy use database • Long-term outlook on energy demand and supply to 2020, including energy demand by sector, energy supply by fuel type, energy pricing, and greenhouse gases • Estimates of alternative fuel use • National Household Energy Use Survey • Fuel use of new vehicles and in-use vehicles • Energy intensity by industrial sector	• Energy use data at the city level, between central city and suburbs • Risks to human health from fuel use emissions
Mining	• Mining statistics on production employment, dollars earned, and exports • SO_2 emissions data • Site-specific provincial/territorial data	• No regular national reporting (no time series) of area of land used, tonnage, area of tailings, pits, quarries, and abandoned mine sites

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Table 16.5 (continued)
Data availability for state of the environment reporting

Component or activity	Data availability	
	Strengths	Gaps
Transportation	• Vehicle–kilometres, passenger–kilometres, fuel use, CO_2 emissions by mode (car, bus, rail, air), 1950–1994 • Contribution of the transportation sector to NOx, VOCs, CO_2 emissions trend data • Trend data on new vehicle fuel efficiency and in-use vehicle fleet fuel efficiency • Public transit operating data by urban centre • Motor vehicle registrations by urban area • Journey to work data (1981 and 1991 censuses) by urban area • Recently initiated National Private Vehicle Use survey will help fill data gaps • Compilation of sustainable transportation initiatives	• Vehicle–kilometres, passenger–kilometres (car, bus), and in-use vehicle fuel efficiency (car) based on estimates and assumptions; ongoing survey needed for vehicle occupancy, vehicle–kilometres, and fuel use • Journey to work data by urban area and subarea may not be readily available (1996 Census) • Land area in city devoted to transportation • Urban versus intercity auto travel not tracked nationally • Differences between the inner city/suburbs/urban fringe in auto ownership, distance driven, public transit use, journey to work, etc. • Ongoing monitoring of sustainable transportation initiatives
Solid waste	• Total solid waste, municipal solid waste (generation, diversion, disposal), 1988 and 1992, by type of material (e.g., glass, aluminum, and yard waste), national level only • National municipal solid waste survey, centres over 5 000, 1993 only • National Packaging Survey, 1988, 1990, and 1992 • National Household and Environment Survey — availability and use of recycling programs, 1991 and 1994 • Selected municipal waste composition studies	• No consistent solid waste management measurement system at the provincial/municipal level across Canada • Lack of consistent definitions • Data available for only one or two points in time; new surveys may not continue
Toxic substances, contaminated sites	• National Pollutant Release Inventory • Priority Substances List under *Canadian Environmental Protection Act* • Preview of new substances through the new Substances Notification Regulation • Accelerated Reduction/Elimination of Toxics (ARET) program (78 substances) • Monitoring of regulated contaminants in air and sediments, at effluent source in water, and in indicator species	• More research needed on the persistent, widespread, low-level effects of contaminants on the ecosystem and on human health • Data on the number of contaminated sites are sparse and not nationally consistent
Urban Canada	• Water: water use and wastewater treatment (1983 to present) • Air: National Air Pollution Surveillance Network of 55 localities for TSP, SO_2, NO_2, CO, O_3 (1979 to present) • Solid waste management (1993) • Green space (nine centres, 1991 only) • Transit supply and demand: Canadian Urban Transit Association (annual) • Housing supply: Canada Mortgage and Housing Corporation • Industrial structure: census • Rural–urban land use change (1966–1986) • Municipal SOE reporting in selected centres • Compendia of municipal environmental initiatives (some are one-time only)	• No nationally consistent trend data at the urban level for urban land use, green space, tree cover, ecologically significant areas, municipal waste management, contaminated land, energy use, vehicle use • Some of these data are available for individual urban centres • Municipal SOE reporting in a wider range of urban centres • Rural–urban land use change data not available since 1986

continued on next page

Table 16.5 (continued)

Data availability for state of the environment reporting

Component or activity	Data availability	
	Strengths	Gaps
Lifestyles, consumption	• Ecological footprint concept developed to facilitate comparison of consumption using a common unit of measurement • Population, household, and housing type: census • Behaviour regarding environmental issues: Household and Environment Survey (1991 and 1994) • Consumption patterns and use of "environmental" products: Family Expenditures Survey, Household Facilities and Equipment Survey • Attitudes towards environmental issues: various private polling firms	• There are some difficulties in obtaining the necessary data to calculate the ecological footprint, particularly as a trend over time • Environmental actions of households in greater detail (e.g., by age group, geographic location) • Household expenditures on green products and hazardous products • The motivations for particular lifestyle patterns

Note: Abbreviations used are as follows:

CFCs: chlorofluorocarbons
CO: carbon monoxide
CO_2: carbon dioxide
IUCN: World Conservation Union
NAWMP: North American Waterfowl Management Plan
NO_2: nitrogen dioxide
NOx: nitrogen oxides
O_3: ozone (ground-level)
SO_2: sulphur dioxide
SOE: state of the environment
TSP: total suspended particulates
VOCs: volatile organic compounds

mental Indicators Program since a preliminary set was produced in 1991. Good indicators are sensitive to change, supported by reliable data, and understood by intended users. Consequently, consultations and partnerships with federal, provincial, university, and nongovernmental organization stakeholders have been a fundamental part of the indicator development process. Thus far, indicators have been published for 9 of the 16 environmental issues, including stratospheric ozone depletion, climate change, toxic contaminants, acid rain, urban environmental quality, marine fish resources, forest resources, energy consumption, and transportation (Table 16.6). But this program is also hampered by the dearth of accurate, nationally consistent, time series information, particularly on an integrated, ecosystem basis.

A task group of the Canadian Council of Ministers of the Environment is developing a core set of indicators for environmental reporting using the work of the National Environmental Indicators Program as a basis. This set focuses on measuring progress in seven priority areas: climate change, air quality, stratospheric ozone depletion, contaminated sites, solid waste, hazardous waste, and water use. No monitoring systems are in place for many indicators, whereas data for others are collected by industries and governments using a wide variety of methods and measurements. The goal of the task group is to standardize the types of indicators used by federal and provincial/territorial governments and other agencies across Canada and to encourage common methods.

Industry-specific indicators may also be useful in resource management in the future. Canada has led the international task force of the World Tourism Organization in developing and testing indicators of sustainable tourism. These indicators deal with the stresses (including environmental degradation) that tourism brings to fragile destinations and tourism industry responses to these stresses. The Canadian Council of Forest Ministers (1995) has identified 6 criteria and 83 indicators to measure sustainable forest management under the National Forest Strategy. This initiative reflects the continuing shift of forest policy in Canada from sustained timber yield to sustainable forest ecosystem management. The first national report on the implementation of criteria and indicators of sustainable forest management is expected by the end of 1996. The agricultural sector in Canada is also working on the development of sustainability indicators.

Is there enough of the right information to judge whether Canadian activities as a whole are sustainable? Can critical stresses and responses be reliably and cost-effectively monitored? The answer is "not yet," and the prospects for obtaining many key data sets are not promising. For some specific environmental issues, such as toxic contamination in the Arctic and urban air pollution, more effective monitoring systems are providing valuable information. However, for many equally important areas of concern, the information needed to make effective decisions continues to be lacking.

Overall, although the quality of some data is improving, the quantity, particularly of integrated data on ecosystems, is not. Indeed, in some cases, there have been significant reductions in the availability and coverage of time series data to assess progress towards sustainability.

As a result, there is not sufficient information on which to base a conclusive assessment of whether the world in general — and Canada in particular — is on, or is even approaching, an environmentally and economically sustainable path. Without improved monitoring and scientific research to provide essential data, the ability to find this path will continue to be compromised.

Conclusion

There is little doubt that, in general, the environment is now under more stress both globally and nationally than it was five years ago. The combination of increasing population at home and abroad, continuing economic growth that is largely dependent on natural resource use, an important, yet moderate range of technological improvements in environmentally sound production of various goods, and generally unchanged consumption patterns and expectations means that the sustainable use of Canada's resources, species, and ecosystems continues to be a challenging goal — one requiring continuous dialogue, innovation, commitment, and effort.

Although Canada's progress towards the stabilization of greenhouse gas emissions under the United Nations Framework Convention on Climate Change is uncertain, Canada has, thus far, achieved its other national and international objectives for phasing out ozone-depleting chemicals and reducing sulphur dioxide emissions, met its interim targets for reductions in packaging and solid waste, and made progress in a short time in creating new protected areas (see Table 16.4). Nevertheless, although the achievement of this limited and specific set of objectives is a real accomplishment, it is only a first step. Many challenges remain, either to reach the more stringent long-term targets necessary to achieve sustainability in these areas or to devise, agree upon, and meet sustainability objectives for other environmental components, resource sectors, and ecosystems.

Changes in environmental conditions and stresses in Canada vary significantly from one ecozone to another. The Arctic and Taiga ecozones are being subjected to environmental stresses as a result of the long-range transport of pollutants from the temperate and tropical regions. The more densely settled ecozones, particularly areas close to the major urban and industrial regions in Canada and across the U.S.

Table 16.6
Framework for a national set of environmental indicators

Theme	Issue	Examples of indicators
Ecological life support systems	• Stratospheric ozone depletion • Climate change • Toxic contaminants in the environment • Biodiversity change • Acid rain • Marine ecosystems • Forest ecosystems	• Global atmospheric concentrations of ozone-depleting substances • Carbon dioxide emissions from fossil fuel use • Contaminant levels in Double-crested Cormorant eggs: DDE, PCBs, dioxins, furans * • Wet sulphate deposition: area receiving ≥20 kg/ha per year * *
Human health and well-being	• Urban environmental quality – Urban air quality – Urban water use and wastewater treatment – Urban green space • Freshwater quality	• Number of hours ground-level ozone exceeded objective • Municipal population served by wastewater treatment * *
Natural resources sustainability	• Marine fish resources • Forest resources • Agricultural resources	• Abundance (spawning biomass) of Pacific Herring stocks • Regeneration after harvest: cumulative area regenerated to commercial species *
Pervasive influencing factors	• Energy consumption • Transportation • Solid and hazardous waste generation • Population growth and lifestyle patterns	• Consumption of energy; fossil fuel consumption • Fuel efficiency of new automobiles; urban transit and auto use * *

* Indicators are under development or consideration.

Notes: 1. A series of indicators have been developed for each issue. Only one or two examples are provided per issue. Examples used are selected from several categories based on the Stress–Environmental condition–Societal response model.
2. Abbreviations used are as follows:
DDE: dichlorodiphenyldichloroethylene
PCBs: polychlorinated biphenyls

Source: National Environmental Indicators Program, State of the Environment Directorate, Environment Canada.

border, are being stressed by population growth and industrial expansion. In between, in ecozones like the Boreal Shield, Atlantic Maritime, and Pacific Maritime, the main stresses tend to come primarily from resource extraction and, in some localities, urbanization. Canada's ecological footprint remains large relative to that of most countries, and it continues to grow.

Areas in which progress towards sustainability has been observed over the past five years have tended to be those, such as forestry management and agriculture, in which environmental and economic goals coincide. Major changes in consumer behaviour towards more environmentally sound expectations and practices, as advocated under *Agenda 21*, have been slow to occur. Similarly, many public and private institutions have been slow to adopt more environmentally sensitive policies and practices, thus providing little incentive for individuals, firms, and communities to act in a more environmentally sustainable manner. There have, however, been continuing technological improvements that have resulted in reduced environmental impacts. For example, although environmentally costly, single detached homes remain in demand, energy-saving technologies (e.g., the R-2000 standard for insulation and windows, high-efficiency furnaces, and heat pumps) are increasingly available to purchasers of these homes.

The general public has shown a willingness to undertake activities that benefit the environment (such as recycling, composting, and tree planting) where it is straightforward to do so. Similarly, consumers are showing a willingness to purchase products (e.g., low-flow showerheads and energy-conserving light fixtures) that have environmental advantages and cost the same as or less than competing products. Moreover, where economic instruments are applied in conjunction with education (e.g., water pricing by volume and increased energy prices in the late 1970s), positive changes in consumption patterns have been quick to follow. Some consumers are also prepared to spend extra to obtain a product that they believe has fewer negative environmental effects than alternative products, but this group remains a small part of the overall market.

The efficiency of production techniques has continued to increase over the past five years, resulting in less waste, fewer pollutants, and better-designed products. The intensification of global competition and increased consumer demand for clean technologies and responsible management appear likely to continue the pressure for improvements in environmental performance. Still, if sustainability is to be achieved, the emphasis in business will soon have to shift away from short-term profitability and towards long-term goals that explicitly embody integrated economic and environmental objectives. (Current methods of discounting for capital projects, for example, could be amended to incorporate long-term environmental effects and risks.) In addition, it is important to note that cooperative problem-solving and voluntary action may prove to be of equal value to, or even of greater value than, government-imposed requirements in changing consumer and corporate behaviour.

Progress towards sustainability, as assessed within the framework of the three core goals of the World Conservation Strategy, has been uneven. Threats to the *maintenance of essential ecological processes and life support systems*, the first goal of the World Conservation Strategy, continue to be a concern. Although concentrated stress on particular systems has been reduced through direct action (as in the case of the St. Lawrence River or Hamilton Harbour), many ecosystems remain under pressure as a result of the widespread production of contaminants and waste and their effects on atmospheric change, water quality, and land. There are some promising developments, however, with respect to the second goal of the World Conservation Strategy, *preservation of biological diversity*, and the integration of biodiversity concerns into land use planning and management. The third goal, *sustainable use of species and ecosystems*, continues to be a challenge. This is not to deny the growing use of practices (such as reforestation, cover cropping, and the recycling of wood and metal products) that contribute to more sustainable resource management. However, as the collapse of the Northern Cod fishery shows most dramatically, the sustainability of some of our most important resources and of the communities that depend on them is still an elusive goal.

The state of Canada's environment — 1991 noted that Canada was at a crossroads, where it faced a choice between continuing along the same road that has created current environmental stresses or choosing a new, more sustainable, path (Government of Canada 1991). That path is still in view, and, whereas some have chosen to follow it, many have not. That does not mean, however, that Canadians do not place a high priority on environmental stewardship. As the polling firm Environics Research has observed, "Canadians have an extremely low level of tolerance for any movement away from a high level of environmental responsibility and activity by government or business" (Environics Research, cited in Environment Canada 1995/1996).

Although Canada's environmental record is among the best in the world, Canadians still face some significant environmental challenges. Some of these are associated with past environmental debts; others are connected with emerging evidence of new areas of concern and with changing institutions. Environmental debts have accrued in the form of contaminated sites, polluted ecosystems, depleted fish stocks, and residual contaminants in soils. New concerns regularly arrive, such as fine particulates, new toxic substances, and unwelcome surprises relating to the spread of contaminants throughout the world. Addressing such concerns will require signal effort in Canada and abroad. The size of the challenge is magnified by the rapid changes that are now occurring in basic institutions such as government, as Canadians reexamine the means available to them to deliver services and to manage common resources. How can we effectively mobilize the effort needed to address current and emerging concerns when roles are so rapidly changing and traditional sources of funding and leadership are also being reduced and reassessed?

To add to these difficulties, many Canadians remain influenced by social norms that define the good life in terms of material abundance. Consequently, they are not yet ready to alter their expectations or rethink what constitutes an adequate standard of living, as they must if they are to make the difficult choices that sustainability demands. These choices relate to fundamental considerations such as how much material consumption on an individual and societal basis is enough, how resources can best be equitably distributed on a global basis, and how resource consumption and pricing should reflect environmental costs and intergenerational equity. These issues, in turn, raise a number of more specific questions. Can Canadians and their governments find the formula that will yield continued economic well-being while maintaining the integrity of the ecological system that supports the economy? Can we develop production systems, industrial codes of practice, fuel efficiency standards, and building codes, for example, that are more efficient and do not undermine ecological integrity? Can governments further develop frameworks and regulations that provide a basis for sustainability through their influence on millions of individual decisions about such small but ecologically crucial choices as where to live and how to travel to work?

Achieving the sustainability goals of the World Conservation Strategy, the Brundtland Commission, and *Agenda 21* will involve hard choices and fundamental changes for both governments and individuals. Yet, along with the rest of the world, Canadians have still to come to terms with these issues. Individually and collectively, we remain largely at the talking or planning stage over whether and how these changes should be implemented — and it is clear that this stage is not sustainable.

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Glossary of Selected Terms

Italicized terms are defined or explained elsewhere in the Glossary; those in **bold** typeface are considered as synonyms or related terms.

A

abiotic: Refers to all physical elements of an *ecosystem*, including, for example, climate, soil, water, geology, physiography, ice, and nonliving organic matter like peat (E.B. Wiken and A.M. Turner, State of the Environment Directorate, Environment Canada, personal communication).

absorption: The incorporation of a substance into a solid or liquid body (Demayo and Watt 1993). See also *adsorption*.

acidic deposition (includes **acid rain** and other forms of **acidic precipitation**): Refers to deposition of a variety of acidic pollutants (acids or acid-forming substances) on *biota*, land, or waters of the Earth's surface. Deposition can be in either wet forms (e.g., rain, fog, or snow) or dry forms (e.g., gas or dust particles).

acid mine drainage: Low-*pH* drainage water from certain mines, usually caused by the oxidation of sulphides to sulphuric acid (Demayo and Watt 1993). Mine drainage can also contain high concentrations of metal ions.

acute toxicity: Severe biological harm or death produced in an organism by a substance within a short time after exposure (Demayo and Watt 1993). See also *chronic toxicity*.

adsorption: Surface retention of solid, liquid, or gas molecules, atoms, or ions by a solid or liquid. Adsorption onto suspended or bottom sediments is an important process in the removal of *pesticides* and other *organic compounds* from the water column of rivers, lakes, and oceans (Demayo and Watt 1993). See also *absorption*.

aerosols: Minute mineral particles suspended in the atmosphere, onto which water droplets or crystals and other chemical compounds may adhere. Both natural processes and human activities emit aerosols. Aerosols also affect the *energy balance* between Earth and its atmosphere by absorbing, scattering, or reflecting solar radiation back to space (Environment Canada 1995).

agroecosystem: An ecosystem managed for the purpose of producing food, fibre, and other agricultural products, comprising domesticated plants and animals, *biotic* and *abiotic* elements of the underlying soils, drainage networks, and adjacent areas that support native vegetation and other wildlife (University of Guelph 1994).

air contaminant: Any solid, liquid, gas, or odour or a combination of any of them that, if emitted into the air, would create or contribute to *air pollution* (Government of Canada 1988).

air pollution: A condition of the air, arising wholly or partly from the presence therein of one or more *air contaminants*, that endangers the health, safety, or welfare of persons, interferes with normal enjoyment of life or property, endangers the health of animal life, or causes damage to plant life or property (Government of Canada 1988).

algal bloom: See *bloom*.

alien (also known as **exotic**, **introduced**, or **nonnative**): Refers to any organism that enters an *ecosystem* beyond its normal range through deliberate or inadvertent introduction by humans. Includes *genetically modified organisms* (living modified organisms) that result from *biotechnology* (Federal–Provincial–Territorial Biodiversity Working Group 1995).

allowable annual cut: The amount of timber that is permitted to be cut annually from a specified area (Natural Resources Canada 1994). The allowable annual cut is used to regulate the harvest level to ensure a long-term (i.e., sustainable) supply of timber.

ammonia nitrogen: Nitrogen in the form of ammonia (NH_3). See also *nitrogen fixation*.

anadromous: Characterizes migrating fish growing in the sea and ascending freshwater streams to spawn (Demayo and Watt 1993).

analogue: In climate change studies, researchers look for past situations that had characteristics similar to those of present or future scenarios. These are called *climate analogues* (Environment Canada 1995).

anoxia: The absence of oxygen, which is necessary to sustain most life. In *aquatic ecosystems*, this refers to the absence of dissolved oxygen in water (Environment Canada et al. 1988).

anthropocentric (also known as **homocentric**): Any human-oriented perspective of the environment, but usually used to emphasize a distinction between humans and nonhumans (Meffe et al. 1994). For example, assessing a forest in terms of its potential timber value would be an exclusively anthropocentric perspective. See also *biocentric*.

anthropogenic: Refers to influences that originate from humans (Wildlife Advisory Council 1993).

antifouling agents: Various chemical substances added to paints and coatings to combat mildew and crustaceous formations, such as barnacles, on the hulls of ships.

aquaculture: The marine or freshwater cultivation of finfish or shellfish (Wildlife Advisory Council 1993).

aquatic: Pertains to both marine and freshwater *ecosystems*.

B

***Bacillus thuringiensis* (B.t., Bt, or BT)**: A biological insecticide that was developed in Canada (Natural Resources Canada 1994). This bacterium, which occurs in soils everywhere, is sprayed on trees against the Spruce Budworm and other similar insects. The subspecies *Bacillus thuringiensis israelensis* (BTI) has been used by the city of Red Deer, Alberta, as a biocontrol agent for two *species* of mosquitoes that bite humans.

background extinction rate: Historical rates of extinction due to environmental causes not influenced by human activities, such as the rate of species going *extinct* because of long-term *climate change* (Meffe et al. 1994).

balance of trade in goods and services: *Exports of goods and services* less *imports of goods and services* (Statistics Canada 1994).

benthic: Of or living on or in the bottom of a water body (Upper Great Lakes Connecting Channels Study, Management Committee 1988). See also *benthos* and *pelagic*.

benthos: Organisms living on the bottom of bodies of water (Demayo and Watt 1993).

bioaccumulation: General term describing a process by which chemical substances are ingested and retained by organisms, either from the *environment* directly or through consumption of food containing the chemicals (Government of Canada 1991). See also *bioconcentration* and *biomagnification*.

biocentric: The view or perception that all living organisms on Earth have intrinsic value and that humans are in no way superior to other *species* (Environment Canada 1993). See also *anthropocentric*.

biochemical oxygen demand (BOD): A measure of the quantity of oxygen used in the biochemical oxidation of compounds containing carbon and nitrogen in a specified time, at a specified temperature, and under specific conditions. The standard measurement is made for five days at 20°C (Demayo and Watt 1993).

bioconcentration: Ability of an organism to selectively accumulate certain chemicals, elements, or substances within its body or within certain cells. A process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill) and elimination (Wells and Rolston 1991). See also *bioaccumulation* and *biomagnification*.

biodegradability: Characteristic of a substance that can be broken down by *microorganisms* (Demayo and Watt 1993).

biodegradable: Capable of being broken down by living organisms into inorganic compounds (Arms 1990).

biodegradation: Biochemical process for the breakdown of large, complex *organic compounds* into simple molecules (Demayo and Watt 1993).

biodiversity (biological diversity): The variability among living organisms from all sources, including, inter alia, terrestrial, marine, and other *ecosystems* and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems (Federal–Provincial–Territorial Biodiversity Working Group 1995).

biodiversity indicators: *Indicators* or measures that allow the determination of the degree of biological or environmental changes within *ecosystems*, *populations*, or groups of organisms over time and space (Federal–Provincial–Territorial Biodiversity Working Group 1995).

biodiversity prospecting: The exploration of biodiversity for commercially valuable genetic and biochemical resources (Reid et al. 1993).

bioenergy: Energy that is produced from *organic matter* (both plant and animal) by burning or by a bioconversion method such as fermentation (Natural Resources Canada 1994).

biological diversity: See *biodiversity*.

biologically available: The physical or chemical form of a substance that can be directly used by an organism (Demayo and Watt 1993).

biomagnification: Cumulative increase in the concentration of a substance in successively higher levels of a *food web* (Environment Canada et al. 1988). See also *bioaccumulation* and *bioconcentration*.

biomass: Quantity of living matter in a defined area expressed in units of living or dead mass (Demayo and Watt 1993). Typically measured as the weight of all dried *organic matter* in a defined area of a particular *ecosystem*. In the energy field, any form of organic matter (from both plants and animals) from which energy can be derived by burning or bioconversion (e.g., fermentation) (Wells and Rolston 1991).

biosphere: Refers to the biological components of the *ecosphere* (E.B. Wiken and A.M. Turner, State of the Environment Directorate, Environment Canada, personal communication).

biota: Collectively, the living organisms in a given *ecosystem*, including bacteria and other *microorganisms*, plants, and animals (Demayo and Watt 1993).

biotechnology: The application of science and engineering in the direct or indirect use of living organisms or parts or products of living organisms in their normal or modified forms (Government of Canada 1988).

biotic: Refers to the living elements of an *ecosystem*, such as plants and animals (Environment Canada 1993).

bleached kraft pulp mill: A pulp and paper mill that produces coarse white paper of great strength from wood pulp using the chlorine pulping process (Eade 1994).

bloom (also known as **algal bloom**): Rapid growth of certain algal constituents of *plankton* in and on a body of water that is so heavy as to colour the water (Demayo and Watt 1993). The rapid

growth can be fuelled by enrichment of *nutrients*, such as phosphorus and nitrogen.

BOD: See *biochemical oxygen demand*.

buffer zone: An area in a reserve or other protected area surrounding the central *core zone*, in which nondestructive human activities such as *ecotourism*, traditional (low-density) agriculture, or extraction of renewable natural products are permitted (Meffe et al. 1994).

C

canopy (tree): The more-or-less continuous cover of branches and foliage formed by the crowns of adjacent trees (Natural Resources Canada 1994).

carbon balance: The concentration of carbon released into the atmosphere compared with the amounts stored in the Earth's oceans, soil, and vegetation (Natural Resources Canada 1994).

carbon dioxide: One of the *greenhouse gases*, which is released to the atmosphere by both natural and human activities. Although it is reabsorbed by the *biosphere* in 50–200 years, while in the atmosphere it is an effective radiator of energy and contributes to the *greenhouse effect* (Environment Canada 1995).

carbon monoxide (CO): A colourless, odourless, and tasteless gas released primarily by incomplete combustion of *fossil fuels* (especially by automobiles). At low doses, carbon monoxide impairs reflexes and perception; at high concentrations, it can cause unconsciousness and death (Greater Vancouver Regional District 1994).

CFCs (chlorofluorocarbons): Any of several simple gaseous compounds that contain carbon, chlorine, fluorine, and sometimes hydrogen. Several forms of these gases are artificially produced and have been used as refrigerants, *aerosol* propellants, and cleaning solvents and in the manufacture of plastic foam. They are suspected of causing *ozone* depletion in the *stratosphere* and, being effective radiators of energy, are strong *greenhouse gases*.

chlor-alkali plants: Plants that produce chlorine and caustic soda by electrolysis of brine (adapted from Eade 1994).

chlorinated organic compounds: See *organochlorine compounds*.

chlorophenols (also known as **chlorinated phenols**): Group of *toxic* chemicals created by the chlorination of *phenols* (e.g., pentachlorophenol). Used as preservatives in paints, drilling muds, photographic solutions, hides and leathers, and textiles. Also used as herbicides and insecticides and, most commonly, for wood preservation (Wells and Rolston 1991).

chronic toxicity: A measurable, but not totally disabling, effect produced in an organism by a substance over a relatively long period (Demayo and Watt 1993). The end result of chronic toxicity can be death, although the usual effects are *sublethal* (e.g., inhibition of reproduction or growth).

clear-cutting: A forest management practice that involves the complete felling and removal of a stand of trees (Natural Resources Canada 1994). Clear-cutting may be done in blocks, strips, or patches.

climate change: An alteration to measured quantities (e.g., precipitation, temperature, radiation, wind, cloudiness) within the climate system that departs significantly from previous average conditions and is seen to endure, bringing about corresponding changes to *ecosystems* and socioeconomic activity (Environment Canada 1995).

climate element: A discrete, perceptible, and measurable property of climate, such as temperature, rainfall, wind, and cloudiness (Environment Canada 1995). A "derived element" is an element computed from an observed climate element. For example, "the growing season" is derived from measurements of temperature.

climate fluctuation: A climatic event (e.g., a cold summer) that may be perceived initially as a beginning of *climate change* but later, as conditions revert to the previous regime, is understood to be a short-term occurrence (Environment Canada 1995).

climax species: *Species* of trees or other vegetation often found in a forest *ecosystem* at the final stage of its development (Natural Resources Canada 1994).

coliform bacteria: Group of bacteria predominantly inhabiting the intestinal tracts of humans and other warm-blooded animals, but also occasionally found elsewhere (Demayo and Watt 1993). The total coliform group is commonly used as an *indicator* of the sanitary quality of water, because ingestion of these bacteria in drinking water can result in diseases such as cholera.

commons: Originally referred to lands in medieval Europe that were owned by townships rather than by private individuals. Now used to include any exploitable resource that is not privately owned (Meffe et al. 1994).

compliance monitoring: Surveillance to ensure conformity to a law, regulation, or guideline (Demayo and Watt 1993).

conservation: The maintenance or *sustainable use* of the Earth's resources in a manner that maintains *ecosystems*, *species*, and *genetic diversity* and the evolutionary and other processes that shaped them. Conservation may or may not involve the use of resources; that is, certain areas, species, or *populations* may be excluded from human use as part of an overall landscape/waterscape conservation approach (Federal–Provincial–Territorial Biodiversity Working Group 1995).

contamination: Introduction of any undesirable foreign substance — physical, chemical, or biological — into an *ecosystem*. Does not imply an effect (see *pollution*). Usually refers to the introduction of human-made substances (adapted from Wells and Rolston 1991).

core zone: Within a larger protected area (reserve, park, etc.), an area of critical importance in which development and other kinds of disruptive activities are prohibited (Meffe et al. 1994).

corridor: With respect to *ecosystems* and ecosystem functions, the naturally vegetated or potentially revegetated areas that link or border natural areas and provide ecological functions such as hydrological flow, habitat, passage, connection, or buffering from impacts due to activities in adjacent areas (adapted from Ontario Ministry of Municipal Affairs 1994). Corridors can occur across or along uplands, lowlands, or slopes; valley, ravine, and river or stream corridors can exist as landform depressions that usually have water flowing through or standing in them for some period of the year.

country food: A diet of local meat and fish (e.g., seal, whale, Caribou, and Arctic Charr) and wild plants gained through subsistence harvest (adapted from Environment Canada 1994).

cumulative effect: The effect on the environment that results from the incremental impact of a proposed action when added to other past, present, and reasonably foreseeable future actions (Kaufmann et al. 1994).

D

DDD (dichlorodiphenyldichloroethane): Breakdown product of *DDT*.

DDE (dichlorodiphenyldichloroethylene): Breakdown product of *DDT*. DDE is produced in most animals when the body attempts to rid itself of DDT. DDE is routinely measured rather than only DDT, because DDE is the most fat-soluble of the DDT breakdown products; thus, of all the compounds that make up total DDT (DDT and its metabolites), DDE is the most easily measured in the fat of animals or in eggs (Bishop and Weseloh 1990).

DDT (dichlorodiphenyltrichloroethane): Synthetic insecticide introduced for widespread use just after World War II to control malaria (Forestry Canada 1993). Because this *organochlorine compound* is *persistent*, tends to *bioaccumulate*, and is known to induce cancer, most uses of DDT were banned in 1974. Registration of all DDT products was discontinued in 1985. However, the use and the sale of existing stocks of DDT products were allowed until 31 December 1990 (Bishop and Weseloh 1990).

deciduous: Characterizes plants that lose their leaves annually, triggered by ecological factors such as temperature, lack of water, and day length (National Vegetation Working Group [Canada Committee on Ecological Land Classification] 1990).

degree-days: The difference, in Celsius degrees, between the air temperature for a given day (usually the mean daily temperature) and an established reference temperature. Degree-days can serve as an index for various purposes. For example, **growing degree-days** are used as an index of growth potential in agriculture and are commonly calculated as the number of Celsius degrees by which the mean daily air temperature exceeds 5°C. **Heating degree-days** are used as an index of space heating requirements and are usually calculated as the number of Celsius degrees by which the mean daily air temperature falls below 18°C. Daily degree-day values are usually summed over a period of interest, such as a year. As a specific example, suppose the daily maximum and minimum air temperatures were 20°C and 10°C, respectively. The daily mean would then be 15°C. Growing degree-days for that day would therefore be the mean, 15°C, minus the reference value of 5°C, or 10°C. Heating degree-days would be the reference value of 18°C minus the mean temperature, 15°C, or 3°C.

de-inking: A process that removes the inks, clays, binders, and other contaminants from waste papers so that the fibres can be recycled (Natural Resources Canada 1994).

dieldrin: Synthetic *pesticide*, in use since 1948 as an agricultural soil and seed treatment to kill fire ants, grubs, wireworms, root maggots, and corn rootworms. By 1975, use was restricted, and now dieldrin can be used only for termite control (Bishop and Weseloh 1990).

dioxins and furans: Dioxin is the popular name for a class of *organochlorine compounds* known as polychlorinated dibenzo-p-dioxins (**PCDDs**). Dioxins are produced as by-products along with furans or, more accurately, polychlorinated dibenzofurans (**PCDFs**), which are also organochlorine compounds. Only a few of the 75 PCDDs and 135 PCDFs are highly *toxic*. The most toxic dioxin is 2,3,7,8-tetrachlorodibenzo-p-dioxin (**2,3,7,8-TCDD**, or simply **TCDD**), although tolerance to this compound varies considerably among *species* (Bishop and Weseloh 1990). Dioxins and furans are formed either as by-products during some types of chemical production that involve chlorine and high temperatures or during combustion where a source of chlorine is present. Elevated levels of 2,3,7,8-TCDD in *ecosystems* are linked to *effluents* from previous 2,4,5-trichlorophenol manufacturing, such as Love Canal. Dioxins, including 2,3,7,8-TCDD, can also occur in airborne *particulate* material from incinerators that burn trash containing chlorinated compounds and in exhaust from diesel engines. Chlorine bleaching of kraft wood pulp is another source of 2,3,7,8-TCDD (Bishop and Weseloh 1990).

disturbance: A discrete event, either natural or human induced, that causes a change in the existing condition of an ecological system (Kaufmann et al. 1994).

disturbance pattern: Arrangement of *disturbances* over space and time (Kaufmann et al. 1994).

domesticated or cultivated: Refers to *species* in which the evolutionary process has been influenced by humans to meet their needs (Federal–Provincial–Territorial Biodiversity Working Group 1995).

drainage basin: See *watershed*.

dry deposition: See *acidic deposition*.

E

ecodistrict: See *ecozone*, *ecoprovince*, *ecoregion*, *ecodistrict*.

eco-labelling: Special product labels that indicate that a product meets standards of environmental soundness that are supported by extensive research into the product's

impact on the environment (Natural Resources Canada 1994).

ecological approach: Natural resource planning and management activities that assure consideration of the relationship among all organisms, including humans, and their environment (Kaufmann et al. 1994).

ecological approach to management: The application of ecological principles to the management of resources to ensure the long-term maintenance of *ecosystem* structure, function, and composition at appropriate temporal and spatial scales (Federal–Provincial–Territorial Biodiversity Working Group 1995).

ecological integrity: The degree to which an *ecosystem* has the ability to be self-sustaining over the long term (E.B. Wiken and A.M. Turner, State of the Environment Directorate, Environment Canada, personal communication).

ecological processes: The actions or events that link organisms, including humans, and their environment, including production, decay, nutrient cycling, disturbance, and successional development (Kaufmann et al. 1994).

ecological succession: See *succession*.

ecoprovince: See *ecozone, ecoprovince, ecoregion, ecodistrict*.

ecoregion: See *ecozone, ecoprovince, ecoregion, ecodistrict*.

ecosphere: Refers to the entire global *ecosystem* that comprises atmosphere, lithosphere, hydrosphere, and *biosphere* as interacting components (E.B. Wiken and A.M. Turner, State of the Environment Directorate, Environment Canada, personal communication).

ecosystem: A dynamic complex of organisms (*biota*), including humans, and their physical environment, interacting as a functional unit (adapted from Federal–Provincial–Territorial Biodiversity Working Group 1995). Ecosystems vary in size and composition and display functional relationships within and between systems. The term may be applied to a unit as large as the entire *ecosphere* or to smaller divisions like the Arctic or even small lakes. Ecosystems apply to the more natural through to heavily human-modified systems. In its broadest sense, an ecosystem includes environmental, social, and economic elements (E.B. Wiken and A.M. Turner, State of the Environment Directorate, Environment Canada, personal communication). The root words of ecosystem are *eco*, a derivative of the Greek term for house or home, and *system*, which addresses the relationships and connections between the biological and physical parts.

ecosystem approach: A comprehensive and holistic approach to understanding and anticipating ecological change, assessing the full range of consequences, and developing appropriate responses. It recognizes the complexity of *ecosystems* and the interconnections among component parts. Among other things, the ecosystem approach recognizes that humans are an integral part of ecosystems and that human social and economic systems constantly interact with other physical and biological parts of the system. Within the context of sustainability, all interactions must be considered in an integrated fashion.

ecosystem diversity: Refers to the variety of *ecosystems* in which *species*, or communities of organisms, occur. It also includes ecosystem structure and function (Environmental Integrations 1994).

ecosystem restoration: Returning an ecosystem from a nonsustainable to a sustainable condition (Kaufmann et al. 1994).

ecosystem sustainability: The ability to sustain biodiversity, productivity, health, resilience to stress, renewability, yields of desired values, resource uses, products, or services from an ecosystem while maintaining the integrity of the ecosystem over time (Kaufmann et al. 1994).

ecotourism: Tourism that has as its focus nature-related, nonconsumptive activities or experiences (e.g., bird-watching or whale-watching) and that helps people appreciate and understand *ecosystems* and their *conservation* (adapted from Environment Canada 1993).

ecozone, ecoprovince, ecoregion, ecodistrict: For land areas, *ecosystem* units defined in the ecological land classification system for Canada; for marine areas, ecosystem units defined in the marine ecological classification system for Canada. For both hierarchical systems, ecozones are the largest units. These are subdivided into progressively smaller units based upon similarities or dissimilarities in ecological characteristics, such as climate, soil or water properties, and *wildlife*. Each ecozone is subdivided into ecoprovinces, each ecoprovince into ecoregions, and each ecoregion into ecodistricts. Ecozones serve as the basic units in this third *State of Canada's environment* report.

effluent: A liquid waste material that is a by-product of human activity (e.g., liquid industrial discharge or sewage), which may be discharged into *ecosystems* (adapted from Wells and Rolston 1991).

endangered: In this report, this term refers to an official designation assigned by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The designation is assigned to any indigenous *species*, subspecies, or geographically separate *population* that is at risk of imminent extinction or extirpation throughout all or a significant portion of its Canadian range. See also *extinct*, *extirpated*, *threatened*, and *vulnerable*.

endemic: Pertains to *species* that are believed to exist only in a specific area (Federal–Provincial–Territorial Biodiversity Working Group 1995). See also *endemism*.

endemism: The situation in which a *species* or other taxonomic group is restricted to a particular geographic region, owing to factors such as isolation or response to soil or climatic conditions (Allaby 1994). Such a taxon is said to be *endemic* to that region.

energy balance or budget: Energy from solar radiation reaching the Earth is balanced over the year by terrestrial heat loss to space. The normal atmospheric *greenhouse effect* regulates the rate of heat loss from Earth by absorbing heat loss energy

and radiating it back towards Earth (Environment Canada 1995).

enhanced greenhouse effect: See *greenhouse effect*.

environment: The components of the Earth, including air, land, and water, all layers of the atmosphere, all organic and inorganic matter and living organisms, and the interacting systems that include all of these components (Government of Canada 1988). Everything that surrounds and affects or influences an organism or a group of organisms; it includes both living and nonliving components as well as both natural and human-built elements (adapted from Environment Canada 1993). See also *ecosystem*.

environmental impact assessment: The critical appraisal of the likely ecological effects of a proposed project, activity, or policy, both positive and negative (Gilpin 1986).

environmental indicator: A selected key statistic that represents or summarizes a significant aspect of the state of the environment, natural resource sustainability, or related human activity. Environmental indicators focus on trends in environmental changes, the stresses that are causing them, how *ecosystems* and their components are responding to these changes, and societal responses to prevent, reduce, or ameliorate these stresses (Kerr 1995). See also *indicator*.

eutrophic: Pertaining to a body of fresh water that is rich in *nutrients* and hence in living organisms (Arms 1990). See also *trophic*, *trophic level*, and *trophic status*.

eutrophication (also known as **nutrient enrichment**): The process of overfertilization of a body of water by *nutrients* that produce more *organic matter* than the self-purification reactions can overcome (Demayo and Watt 1993). Eutrophication can be a natural process or it can be accelerated by an increase of *nutrient loading* to a water body by human activity (Upper Great Lakes Connecting Channels Study, Management Committee 1988). See also *trophic*, *trophic level*, and *trophic status*.

evergreen: Pertains to plants that do not generally shed their leaves annually (National Vegetation Working Group [Canada Committee on Ecological Land Classification] 1990).

exotic: See *alien*.

exports of goods and services: Current receipts from exports of merchandise, travel expenditures of nonresidents in Canada, freight and shipping charges earned on Canadian accounts, and other receipts from services rendered to nonresidents (Statistics Canada 1994). See also *imports of goods and services* and *balance of trade in goods and services*.

ex situ conservation: The *conservation* of components of biodiversity outside their typical *habitats*. Includes such institutions as zoos, museums, botanical gardens, aquariums, and gene banks (Federal–Provincial–Territorial Biodiversity Working Group 1995). See also in *situ conservation*.

extinct: In this report, this term refers to an official designation assigned by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The designation is assigned to any indigenous *species*, subspecies, or geographically separate *population* formerly indigenous (native) to Canada that no longer exists anywhere. See also *endangered*, *extirpated*, *threatened*, and *vulnerable*.

extirpated: In this report, this term refers to an official designation assigned by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The designation is assigned to any indigenous *species*, subspecies, or geographically separate *population* no longer existing in the wild in Canada but occurring elsewhere. See also *endangered*, *extinct*, *threatened*, and *vulnerable*.

F

factor cost: Valuation of factor cost represents the costs of the *factors of production* (Statistics Canada 1994). The valuation is expressed in terms of the expense of the producer, rather than the purchaser. It excludes all indirect taxes, such as sales and excise taxes, customs duties, and property taxes. See also *market prices*.

factors of production: Productive agents that, when combined, create economic output (Statistics Canada 1994). In broad terms, the two factors of production are labour and capital.

feedback: With reference to climate, a regulating mechanism within the climate system that dampens or enhances the effects of a forced change or fluctuation (Environment Canada 1995). Feedbacks that enhance effects are termed "positive," whereas those that dampen them are "negative."

feral: Refers to domestic *species* that have "gone wild" (Environment Canada 1993).

flyway: A geographic migration route for birds, including the breeding and wintering areas that it connects (Lapedes 1978). The Pacific flyway, one of four in North America, runs north–south along the mountainous areas of the west.

food chain: A food relationship in an *ecosystem* in which energy and *nutrients* are transferred through a series of organisms by each stage feeding on the preceding one and providing food for the succeeding stage (adapted from Demayo and Watt 1993). Each stage of a food chain is known as a *trophic level*. The first trophic level consists of the green plants that can undertake photosynthesis, thereby obtaining their energy from the sun. See also *food web*.

food web: A complex intermeshing of individual *food chains* in an *ecosystem* (Wells and Rolston 1991).

fossil fuels: Oil, gas, coal, and other fuels that were formed under the Earth's surface from the fossilized remains of plants and tiny animals that lived millions of years ago.

fragmentation: The disruption of extensive *habitats* into isolated and small patches (Meffe et al. 1994).

fuel (also known as **combustible**): Any form of matter that in its primary use is

combusted or oxidized for the generation of energy (Government of Canada 1988).

full-tree harvesting: A tree harvesting process that includes removing the trunk, branches, and, in some instances, roots from a forest site. In Canada, this process is used to control root diseases (Natural Resources Canada 1994).

furans: See *dioxins and furans*.

G

gene pool: The sum total of genes in a sexually reproducing population (Meffe et al. 1994).

genetically modified organisms: Organisms whose genetic makeup has been altered by the insertion or deletion of small fragments of deoxyribonucleic acid (DNA) to create or enhance desirable characteristics from the same or another *species* (Federal–Provincial–Territorial Biodiversity Working Group 1995). See also *biotechnology*.

genetic diversity: The infinite variation of possible genetic combinations among individuals. Genetic diversity is what enables a *species* to adapt to ecological change (Environment Canada 1993).

genetic resources: Genetic material of actual or potential value (Federal–Provincial–Territorial Biodiversity Working Group 1995).

global warming: See *greenhouse effect*.

greenhouse effect: The preservation of warmth in the Earth–atmosphere system caused by the presence in the atmosphere of certain gases (e.g., water vapour, *carbon dioxide*) that transmit shortwave energy (visible and *ultraviolet radiation*) to the Earth's surface and temporarily absorb and retain heat radiating from the surface, thereby retarding the loss of energy to space (adapted from Environment Canada 1995). The greenhouse effect has been a property of Earth's atmosphere for millions of years, but human activities have added to the amount of atmospheric *greenhouse gases* over recent years. Any increase in warming resulting from human activity is referred to variously as the **enhanced greenhouse effect**, **greenhouse warming**, **greenhouse gas warming**, and **global warming**.

greenhouse gas: A gas that has strong capabilities to absorb longwave energy in the atmosphere and reradiate it, thus contributing to the *greenhouse effect* (Environment Canada 1995).

gross domestic product (GDP): The unduplicated value of production originating within the boundaries of Canada, regardless of the ownership of the *factors of production* (Statistics Canada 1994). Gross domestic product can be valued either at *factor cost* or at *market prices*. See also *real GDP*.

gross national product (GNP): The unduplicated value of production by Canadian-owned *factors of production*, regardless of where it takes place (Statistics Canada 1994). Gross national product can be valued either at *factor cost* or at *market prices*. GNP is an often-used measure of assessing global economic trends.

groundfish (also known as **bottom fish**): Those *species* of fish that normally occur on or close to the seabed (Organisation for Economic Co-operation and Development 1990), such as cod and haddock.

ground-level ozone (also known as **tropospheric ozone**): *Ozone* (O_3) that occurs near the surface of the Earth. It is a pollutant of concern in *smog* because of its *toxic* effects (adapted from Arms 1990).

groundwater: Water occurring below the ground surface, which may supply water to wells and springs (Upper Great Lakes Connecting Channels Study, Management Committee 1988). Groundwater occupies pores, cavities, cracks, and other spaces in bedrock and unconsolidated surface materials (modified from Whitton 1984).

H

habitat: The place or type of site where plant, animal, or *microorganism populations* normally occur (Filion et al. 1993). The concept of habitat includes the particular characteristics of that place, such as climate and the availability of water and other life requisites (e.g., soil *nutrients* for plants and suitable food and shelter for animals), which make it especially well suited to meet the life cycle needs of the particular *wildlife*.

halocarbon: See *halon*.

halon (also known as **halocarbon**): An industrial compound containing carbon and a halogen (usually fluorine, chlorine, or bromine), which is commonly used in fire extinguishers (Allaby 1994). Most are *hydrocarbons* (usually *methane* or ethane) in which atoms of hydrogen have been replaced by atoms of halogens. Halocarbons absorb longwave electromagnetic radiation (i.e., they are *greenhouse gases*); because of their chemical stability, they survive in the atmosphere long enough to enter the *stratosphere*, where they are decomposed by *ultraviolet radiation*, releasing by-products that are implicated in the depletion of *stratospheric ozone*. The two most widely used halocarbons are bromotrifluoromethane (halon 1301) and bromochlorodifluoromethane (halon 1211).

hardwood: Refers to trees that are *deciduous*. Hardwoods belong to the botanical group Angiospermae (Natural Resources Canada 1994).

hazardous waste: Waste that poses a risk to human or ecological health and requires special disposal techniques to make it harmless or less dangerous.

HCB (hexachlorobenzene): C_6Cl_6; used in synthesizing *organic compounds* and as a fungicide. Also known as perchlorobenzene (adapted from Lapedes 1978).

HCH (hexachlorocyclohexane): $C_6H_6Cl_6$; a systemic (meaning that it affects a whole bodily system, such as the nervous system) insecticide poisonous to flies, cockroaches, aphids, and boll weevils. Also known as benzene hexachloride (Lapedes 1978).

HDPE (high-density polyethylene): Rigid plastic, often used for containers for dairy products or shampoo. Accepted in many plastic *recycling* programs.

heavy metal: A metallic element with a relatively high atomic weight (>5.0 specific gravity), such as lead, cadmium, and mercury (adapted from Eade 1994).

hydrocarbons: *Organic compounds* containing only hydrogen and carbon (adapted from Wells and Rolston 1991). Crude oil consists for the most part of a complex mixture of hydrocarbons.

hydrological cycle (also known as the **water cycle**): The complement of processes by which water reaches the Earth from atmospheric precipitation, passes through transport and storage stages on the Earth's surface, and is returned to the atmosphere through evaporation and evapotranspiration (Environment Canada 1995).

I

ice age: A cooling of the global temperature by about 5°C below present values can maintain ice sheets over mid- to high-latitude continental surfaces. This has occurred on several occasions over the past 2 million years. Ice ages are separated by interglacial periods, such as the present Holocene period, which has lasted 10 000 years (Environment Canada 1995).

ice core: In *climate change* detection studies, cores are extracted from deep drill holes in Kalaallit Nunaat (formerly Greenland) and Antarctic ice sheets and include ice layers up to 200 000 years old, as dated by radiocarbon techniques. Included in the ice are traces of metals and atmospheric gases that have been analyzed to show historic temperatures and *greenhouse gas* concentrations over time (Environment Canada 1995).

imports of goods and services: Current payments for imports of merchandise, travel expenditures of Canadians abroad, freight and shipping charges incurred by Canada on foreign accounts, and other payments for services rendered by nonresidents (Statistics Canada 1994). See also *exports of goods and services* and *balance of trade in goods and services*.

indicator: A statistic or parameter measure that, tracked over time, provides information on trends in the condition of a phenomenon and has significance extending beyond that associated with the properties of the statistic itself (Kerr 1995). See also *environmental indicator*.

indicator species: An organism whose presence or absence suggests that certain ecological conditions prevail. An indicator species can be used to monitor how much of a factor is present and how an ecosystem is responding to stresses and changes (Natural Resources Canada 1994).

Indigenous ecological and environmental knowledge: Through a traditional way of life over many generations, Indigenous people in Canada and elsewhere have developed an in-depth knowledge of the *ecosystems* in which they live. As hunters, they occupy the same ecosystems as their prey, and accurate observations and interpretations about *wildlife* behaviour and the land can make the difference between hunting success and failure or between life and death. Aside from hunting, Indigenous people have traditionally spent hours observing and then discussing animals, plants, weather, and other aspects of the ecosystems that they share with wildlife. Lessons were learned, and the knowledge base became fine-tuned through direct experience of a subsistence lifestyle (Environment Canada 1994). See also *traditional ecological knowledge*.

industrial ecology: The network of all industrial processes as they may interact and live off each other, not only in the economic sense, but also in the sense of direct use of each other's material and energy wastes (Ausubel 1992). As in the more traditional use of the term ecology, this term recognizes that there is a constant flow of energy and *recycling* of matter. There is in reality no such thing as *waste* — one industry's by-product becomes the raw material for another. Industrial ecology is an attempt to mimic the structure and function of *ecosystems* in the organization of industrial production. Putting this another way, the premise of industrial ecology is that the industrial economy — which includes raw materials extraction, manufacturing processes, product use, and waste disposal — should, as far as possible, imitate the cycling of materials and energy as it occurs in a natural ecosystem.

infrastructure: Physical structures that form the foundation for development (Ontario Ministry of Municipal Affairs 1994). Infrastructure includes sewage and water works; waste management systems; electric power, communications, transit, and transportation corridors and facilities; and oil and gas pipelines and associated facilities.

inorganic compounds: Compounds not containing a combination of carbon/hydrogen/oxygen as in living things. See also *organic compounds*.

inorganic matter: Matter other than plant or animal. See also *organic matter*.

in situ conditions: Conditions where *genetic resources* exist within *ecosystems* and, in the case of *domesticated or cultivated species*, in the surroundings where they have developed their distinctive properties (adapted from Federal–Provincial–Territorial Biodiversity Working Group 1995).

in situ conservation: The *conservation* of *ecosystems* and the maintenance and recovery of viable *populations* of *species* in their typical surroundings and, in the case of *domesticated or cultivated* species, in the surroundings where they have developed their distinctive characteristics (adapted from Federal–Provincial–Territorial Biodiversity Working Group 1995). See also *ex situ conservation*.

integrated pest management: A broadly based method that uses all suitable control measures to reduce pest-related losses to an acceptable level with the goal of respecting *biodiversity* and reducing risks to ecosystems and human health (adapted from Pest Management Alternatives Office 1995). The ingredients of an integrated pest management program include:

- planning and managing production systems to prevent organisms from becoming pests;

- identification of potential pests;
- monitoring *populations* of pests, beneficial organisms, and all other relevant ecological factors;
- establishment of economic/damage/ action thresholds;
- application of cultural, physical, biological, chemical, and behavioural control measures to maintain pest populations below threshold levels; and
- evaluation of the effects and efficiency of pest control measures used.

integrated resource management: The use of an *ecosystem approach* to the management of two or more resources in the same general area; commonly includes water, soil, timber, range, fish and other *wildlife*, and recreation (Forestry Canada 1989).

Intergovernmental Panel on Climate Change (IPCC): A global *climate change* study group organized jointly by the World Meteorological Organization and the United Nations Environment Programme in 1988 to bring together leading scientists from over 30 countries (Environment Canada 1995).

intrinsic value: The worth of an entity independent from external circumstances or its value to humans; value judged on inherent qualities of an entity rather than value to other entities (Meffe et al. 1994).

introduced: See *alien*.

invasive: Refers to a *species* that has moved into an area and reproduced so aggressively that it has replaced some of the original species (Environment Canada 1993). Examples include Purple Loosestrife and European Starling.

K

kraft pulp mill: Produces coarse brown paper of great strength from wood pulp using the sulphite pulping process (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993). Kraft paper is commonly used to produce corrugated paper (e.g., for boxes) or grocery bags (Forestry Canada 1993). Bleached kraft pulp mills typically use chlorine to produce whiter paper.

L

leaching: Washing out of soluble substances by water passing down through soil. Leaching occurs when more water falls on the soil than is lost by evaporation from the surface. Rainwater running through the soil dissolves mineral *nutrients* and other substances and carries them via *groundwater* into water bodies (adapted from Arms 1990). The leaching of mercury and other *heavy metals* into water supplies is believed to be a serious consequence of *acidic deposition*.

life cycle: Consecutive and interlinked stages of a product or service, from the extraction of natural resources to the final disposal (International Organization for Standardization 1995). It refers to the full sequence of events that begins with the production of the raw material components, through assembly, distribution, consumption or use, and possibly reuse, and ending finally with the disposal and *recycling* of *wastes* (adapted from Mendis 1995).

life cycle approach: An approach to evaluating the environmental impacts of a consumer commodity through examination of the environmental considerations during all phases of the product's life cycle (adapted from Mendis 1995).

life cycle assessment: Systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle (International Organization for Standardization 1995).

lifestyle: The behaviour and activities of an individual on a day-to-day basis that reflect the attitudes and values of the individual or group that he/she is part of. A range of lifestyle characteristics is common to many (but not all) Canadians. Some of these characteristics include going to school, going to work or somehow participating in the wage economy, taking time for leisure activities, access to climate-controlled housing, access to a range of food products, use of a range of electronic products, use of private automobiles, and so on. Individuals can make choices about lifestyles, but these are constrained or conditioned by economic circumstances, available products, infrastructure, technology, and social norms and expectations (adapted from Chapter 2).

loadings: Total mass of contaminants to a water body or to the land surface over a specified time (e.g., tonnes per year of phosphorus) (adapted from Upper Great Lakes Connecting Channels Study, Management Committee 1988).

M

macronutrient: An element, such as potassium or nitrogen, essential in large quantities for plant growth (Lapedes 1978).

market prices: Valuation of market prices is expressed in terms of the prices actually paid by the purchaser (Statistics Canada 1994). It includes indirect taxes, such as sales and excise taxes, customs duties, and property taxes, and also reflects the impact of subsidy payments. See also *factor cost*.

mean: A synonym for "average" (Environment Canada 1995).

methane (CH_4): A *greenhouse gas* emitted to the atmosphere from ecological sources such as *wetlands* but also from a number of human-caused sources, including manure deposits, rice paddies, municipal dumps, coal mines, and leaks from gas wells and pipelines (Environment Canada 1995). Although an effective energy radiator, methane has a relatively short residence time in the atmosphere (a decade).

microorganism: Microscopic one- or multi-celled organism; includes members of the groups bacteria, viruses, yeasts and certain other fungi, algae, and protozoans (Natural Resources Canada 1994).

monitoring: The process of checking, observing, or keeping track of something for a specified period of time or at specified intervals (Soil Conservation Society of America 1982).

monoculture: Cultivation of a single crop or product to the exclusion of other crops or products (adapted from Natural Resources Canada 1994).

N

natural regeneration: See *regeneration*.

nitrogen fixation: Conversion of gaseous (atmospheric) nitrogen (N_2) to compounds such as ammonia (NH_3). Carried out in *ecosystems* mainly by bacteria of the genus *Rhizobium* (Arms 1990). See also *ammonia nitrogen*.

nitrogen oxides (NOx): A group of gases released by *fossil fuel* combustion, forest fires, lightning, and decaying vegetation (adapted from Greater Vancouver Regional District 1994). **Nitrogen dioxide (NO_2)**, a reddish-brown gas with an irritating odour, is one of the key ingredients in *smog*. **Nitrous oxide (N_2O)** is a *greenhouse gas* whose principal source is agricultural soil in a degraded state (Environment Canada 1995).

nonnative: See *alien*.

non-point source: Source of *pollution* in which pollutants are discharged over a widespread area or from a number of small inputs rather than from distinct, identifiable sources (Environment Canada et al. 1988). Examples include eroding croplands, *urban* and suburban lands, and logged forestlands. See also *point source*.

nonrenewable resource: Natural resource that cannot be replaced, regenerated, or brought back to its original state once it has been extracted (International Organization for Standardization 1995). Examples of nonrenewable resources include coal, crude oil, and metal ores.

nutrient: Any element or compound that an organism must take in from its *environment* because it cannot produce it or cannot produce it as fast as it needs it (Arms 1990). As pollutants, any substance or group of substances (e.g., phosphorus or nitrogen) that, if added to water in sufficient quantities, provides nourishment that promotes the growth of aquatic vegetation in those waters to such densities as to degrade or alter or form part of a process of degradation or alteration of the quality of those waters to an extent that is detrimental to their use by any plant or animal, including humans (modified from Environment Canada et al. 1988). An example would be *eutrophication* of a lake.

nutrient enrichment: See *eutrophication*.

O

ocean dumping: The deliberate disposal at sea from ships, aircraft, platforms, or other anthropogenic structures, including disposal by incineration or by any other thermal degradation, of any substance, or the disposal of any substance by placing it on the ice in any area of the sea (Government of Canada 1988).

old-growth forest (also known as **ancient forest**): A stand of mature and overmature trees relatively uninfluenced by human activity (Natural Resources Canada 1994). The stand can contain multiple layers of tree *canopies* and various *species* of trees, a significant number of which are huge and long-lived. Such a forest also usually has many large, standing dead trees and numerous logs lying about the forest floor.

organic compounds: Compounds based on carbon and usually also containing hydrogen, with or without oxygen, nitrogen, or other elements (Wells and Rolston 1991). Organic originally meant "of plant or animal origin," and it is still sometimes used in this way. For example, "organic waste" can mean food scraps, manure, sewage, leaves, etc.; "organic fertilizer" can mean manure; "organic deposits" can mean peat or other plant material in soil; "organic *nutrients*" can mean nutrients derived from decayed plant material. However, now that organic compounds are routinely created by people, the word "organic" is also used to refer to synthetic organic compounds, as in "organic *pollution*" (which can include *toxic* human-made organic compounds). See also *organochlorine compounds*.

organic matter: Plant, animal, or *microorganism* matter, either living or dead.

organochlorine compounds (also known as **chlorinated organic compounds**, **chlorinated organics**, or **organochlorides**): Chlorine-containing *organic compounds*, which may contain oxygen and other elements, such as phosphorus. The term includes many *pesticides* and industrial chemicals (Wells and Rolston 1991). Examples are *dioxins and furans*, *PCBs*, *DDT*, *dieldrin*, *HCB*, and *HCH*. Many of these kinds of compounds tend to be *persistent*, meaning that they do not break down easily in *ecosystems*.

ozone (O_3): A pungent, faintly bluish gas composed of three atoms of the element oxygen. In the lower 10 km of the atmosphere, it occurs as a *pollution* product formed by combining *nitrogen oxides (NOx)* and *volatile organic compounds (VOCs)* in the presence of sunlight (Greater Vancouver Regional District 1994). In this portion of the atmosphere, it is also a *greenhouse gas* (Environment Canada 1995). Above 20 km, it is produced naturally and serves to protect the *biosphere* from damaging *ultraviolet radiation*. See also *ground-level ozone* and *stratospheric ozone*.

P

Pacific flyway: See *flyway*.

PAHs (polycyclic aromatic hydrocarbons): Among the oldest known carcinogens in humans, PAHs are released into *ecosystems* from atmospheric emissions, especially the burning of *fossil fuels*. Sources include thermal power plants, coke ovens, sewage, wood smoke, and used lubricating oils (Wells and Rolston 1991).

paperboard: A term used to describe a variety or group of varieties of board materials used in the production of boxes, folding cartons, and solid fibre and corrugated shipping containers (Natural Resources Canada 1994).

particulate: Anything that can be filtered from the air (Greater Vancouver Regional District 1994). Large particles, such as road dust or pollen, can irritate the eyes, whereas smaller particles (often called "fine particulates") from smoke and fumes can be inhaled into the lungs.

PCBs (polychlorinated biphenyls): In use since 1929, there are 209 PCB isomers that differ from one another in the number and relative position of the chlorine atoms on the biphenyl frame. A small number of the isomers have toxicological properties similar to those of *TCDD* and are thought to account for the bulk of PCB-induced *toxicity* in animals. Their low flammability made them useful as fire retardants in insulating and heat-exchanging fluids used in electrical transformers and capacitors. The same property made them useful as lubricating oils. They were also used as plasticizers and waterproofing agents and in inking processes used to produce carbonless copy paper. Industrial producers of PCBs voluntarily cut back PCB production in 1971. In Canada, PCB uses were regulated in 1977, and importation of all electrical equipment containing PCBs was banned after 1980 (Bishop and Weseloh 1990).

PCDD and PCDF: See *dioxins and furans*.

pelagic: Pertaining to organisms that swim or drift in a sea or lake, as distinct from those that live on the bottom (*benthos*) (Concise Science Dictionary 1984). Includes *plankton*, many fish *species*, and oceanic birds. See also *benthic*.

pentachlorophenol: See *chlorophenols*.

permafrost: Perennially frozen layer in the soil, found in alpine, Arctic, and Antarctic regions (Arms 1990).

persistent: Refers to chemical compounds, such as many *organochlorine compounds*, that do not break down easily in *ecosystems*.

pesticide: A substance, usually chemical, used to kill unwanted plants and animals (Government of Saskatchewan 1991). Includes herbicides, insecticides, algicides, and fungicides (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

pesticide residue: Refers to a *pesticide* that remains in food, soil, and water after application. Many of the 5 000 different chemicals are *toxic* substances that penetrate fruits and vegetables and cannot be washed off (Government of Saskatchewan 1991).

PET (polyethylene terephthalate): A polyester resin used to make films or fibres (Lapedes 1978). A clear plastic that is accepted by many plastic *recycling* programs.

pH: A numerical expression of the concentration of hydrogen ions in solution: pH 0–6.9 is acidic, pH 7 is neutral, and pH 7.1–14 is basic or alkaline.

phenol: C_6H_5OH; a caustic, poisonous, crystalline acidic compound present in coal tar and wood tar.

phenolics: Any of a number of compounds with the basic structure of *phenol* but with substitutions made onto this structure. Phenolics are produced during the coking of coal, the distillation of wood, and the operation of gas works and oil refineries, from human and animal wastes, and from the microbiological decomposition of *organic matter* (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

phytoplankton: Microscopic *aquatic* vegetative life; plant portion of the *plankton*; the plant community in marine and freshwater situations that floats free in the water and contains many *species* of algae and diatoms (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

pioneer species: Tree *species* that establish themselves before other species in a forest area that has recently been cleared by ecological processes such as fire started by lightning or by mechanical means (Natural Resources Canada 1994).

plankton: Collective noun for organisms that drift around in water because they are not capable of swimming against currents in the water (Arms 1990). See also *phytoplankton* and *zooplankton*.

point source: A source of *pollution* that is distinct and identifiable (Environment Canada et al. 1988). Includes smokestacks and outfall pipes from industrial plants and municipal sewage treatment plants. See also *non-point source*.

pollution: The release by humans, directly or indirectly, of substances or energy into *ecosystems* that results or is likely to result in such deleterious effects as to harm living resources and life, be hazardous to human health, hinder human activities, impair the quality of the ecological resources, and reduce amenities (modified from Wells and Rolston 1991).

polynya: An area of open water surrounded by ice; polynyas vary in size and shape and may be caused by a variety of factors, the most important of which are currents, tidal fluctuations, wind, upwellings, or a combination of these forces.

population: A group of organisms of the same *species* living within a specified region (Wells and Rolston 1991).

primary wastewater treatment: First step in sewage treatment to remove large solid objects by screens (filters) and sediment and *organic matter* in settling chambers (Wells and Rolston 1991). See also *secondary wastewater treatment* and *tertiary wastewater treatment*.

protected area: Geographically defined area that is designed or regulated and managed to achieve specific *conservation* objectives (Federal–Provincial–Territorial Biodiversity Working Group 1995).

R

real GDP (gross domestic product): An indicator of overall economic growth in Canada. It is the value of the sum of physical quantities of goods and services produced, converted to a money valuation basis from which the year-to-year change in price has been eliminated (Market Data Group 1994).

recovery: The recovery of energy by using components of *waste* as fuel. Can also refer to the extraction of materials of value from the waste stream. See also *recycling*.

recyclable: Refers to such products as paper, glass, plastic, used oil, and metals that can be reprocessed instead of being disposed of as *waste* (Government of Saskatchewan 1991).

recycling: Set of processes for reclaiming, as a material input to a product or service system, material that would otherwise be disposed of as *waste* (adapted from International Organization for Standardization 1995).

regeneration (also called **reforestation**): The renewal of a tree crop, which can be by the natural occurrences of seeding, sprouting from roots, suckering, or layering (commonly referred to as **natural regeneration**) or by sowing or planting (**artificial regeneration**) (adapted from Natural Resources Canada 1994).

renewable resource: Natural resource that is capable of regeneration (International Organization for Standardization 1995). Renewable resources can essentially never be exhausted, usually because they are continuously produced (e.g., tree *biomass*, fresh water, and fish).

S

second growth: A second forest that develops after harvest of the original forest (Forestry Canada 1989).

secondary wastewater treatment: After *primary wastewater treatment*, removal of biodegradable *organic matter* from sewage using bacteria and other *microorganisms*, inactivated sludge, or trickle filters. Also removes some of the phosphorus (30%) and nitrate (50%) (Wells and Rolston 1991). See also *tertiary wastewater treatment*.

selective logging: A partial-harvest method that removes only the most valuable species of trees or only trees of prescribed size or quality (Natural Resources Canada 1994).

short-wood harvesting: A harvesting method by which a tree is cut down, delimbed, and cut into 1.3-, 2.6-, or 4.8-m lengths before being transported to a mill (Natural Resources Canada 1994).

silviculture: The theory and practice of controlling the establishment, composition, growth, and quality of forest stands to achieve certain management objectives (Natural Resources Canada 1994).

slash burning: Burning the residue on the forest floor that is left after harvesting or stand tending or after accumulating from natural causes (Natural Resources Canada 1994).

smog: Literally a contraction of "smoke" and "fog"; smog includes *ground-level ozone* and numerous other contaminants. It tends to provide a brownish-yellow haze to the atmosphere, especially over *urban* areas (adapted from Greater Vancouver Regional District 1994).

snag: A standing dead tree from which the leaves and most of the branches have fallen (Natural Resources Canada 1994). Snags provide important nesting *habitats* for many *wildlife species*, including woodpeckers, flickers, and other cavity-nesting birds, as well as Ospreys and some other raptors; chipmunks, squirrels, and some other mammals may also occupy natural cavities or abandoned woodpecker holes in snags.

softwood: Pertains to cone-bearing trees with needles or scale-like leaves. Softwoods belong to the botanical group Gymnospermae (Natural Resources Canada 1994).

soil compaction: The compression of soil as a result of vehicle traffic, especially that of heavy equipment (Forestry Canada 1989).

soil erosion: The detachment and movement of soil by the action of wind (wind erosion) and moving water (water erosion) (Lapedes 1978).

SOx: See sulphur oxides.

species: A group of related individuals with common hereditary morphology, chromosome number and structure, physiological characteristics, and way of life, separated from neighbouring groups by a barrier that is generally sexual in nature — i.e., members of different species do not normally interbreed, and, if they do, the progeny are sterile (Demayo and Watt 1993).

species diversity: Refers to the total number of different *species* in a given area (Environmental Integrations 1994).

species richness: The number of *species* in a region, site, or sample (Meffe et al. 1994).

stewardship: Management of natural resources that conserves them for future generations (Meffe et al. 1994). Usually used to distinguish from short-term, utilitarian management objectives.

stratosphere: The layer of the atmosphere between about 10 and 50 km above the Earth's surface within which temperatures rise with increasing altitude (Environment Canada 1995). Contains *stratospheric ozone*, which absorbs potentially harmful *ultraviolet radiation*.

stratospheric ozone: In the *stratosphere*, solar radiation converts some oxygen molecules (O_2) into ozone (O_3). Ozone absorbs much *ultraviolet radiation* and prevents it from reaching the Earth (adapted from Arms 1990).

sublethal: Involving a stimulus below the level that causes death (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

succession (also known as **ecological succession**): Short-term (1 000 years or less) change in a *biotic* community. The process whereby opportunistic plants and animals recolonize an area that has been disturbed (e.g., when a crop field is abandoned and left for nature to redevelop). A series of temporary communities develops according to a pattern that, in the absence of major disturbances, is predictable. The final mature, or climax, stage (an example is an *old-growth forest*) is in equilibrium with (i.e., determined by) the regional climate and the local substratum, topogra-

phy, and water conditions (adapted from Odum 1989).

sulphur oxides (SOx): A group of gases released by the combustion of *fossil fuels* and by natural sources such as volcanoes (Greater Vancouver Regional District 1994). **Sulphur dioxide (SO_2)**, a colourless gas with a pungent odour, irritates the upper respiratory tract in humans and leads to *acidic deposition/acid rain*.

summerfallow: Land left unsown, usually for a season, to conserve moisture in the soil and to allow accumulation of nitrogen (Forestry Canada 1993).

sustainability: The ability of an *ecosystem* to maintain ecological processes and functions, *biodiversity*, and productivity over time (Kaufmann et al. 1994).

sustainable development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development 1987). Development that ensures that the use of ecological resources and *ecosystems* today does not damage prospects for their use by future generations (Canadian Council of Resource and Environment Ministers 1987).

sustainable harvest rate: A rate of harvest that is within an *ecosystem's* natural ability to recover and regenerate (Federal–Provincial–Territorial Biodiversity Working Group 1995).

sustainable use: Use of components of *biodiversity* (i.e., organisms or *ecosystems*) in a way and at a rate that does not lead to the long-term decline of biodiversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations (Filion et al. 1993).

sustained yield: The yield that a forest, cropland, water body, or other resource base can produce continuously at a given intensity of management (Forestry Canada 1991).

synergistic interaction: An interaction that has more than additive effects, such as the joint *toxicity* of two compounds being greater than their combined independent toxicities (Meffe et al. 1994).

T

tailings: Material rejected from a mill after most of the recoverable valuable minerals have been extracted (Whiteway 1990). Tailings are generally finely ground rock particles that are transported as a water slurry to a storage area, known as a **tailings pond**, at the mine site. Usually the tailings composition is similar to the parent ore body and may therefore contain metals, sulphides, salts, or radioactive materials.

TCDD: See *dioxins and furans*.

temperate forest: One of the three main forest types in the world, composed mainly of *deciduous* trees (Natural Resources Canada 1994). The other two types are the northern (boreal), largely *evergreen* forest and the tropical evergreen forest.

tertiary wastewater treatment: Removal of nitrates, phosphates, *organochlorine compounds*, salts, acids, metals, and *toxic organic compounds* after *secondary waste-water treatment* (Wells and Rolston 1991). See also *primary wastewater treatment*.

threatened: In this report, this term refers to an official designation assigned by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The term describes any indigenous *species*, subspecies, or geographically separate *population* that is likely to become *endangered* in Canada if the factors affecting its vulnerability are not reversed. See also endangered, *extinct*, *extirpated*, and *vulnerable*.

timber licence: A licence to cut and remove timber from Crown lands (adapted from Natural Resources Canada 1994).

time series: A sequence of data derived from consecutive observations taken in the same manner and at equal time intervals (Environment Canada 1995).

total ozone: The *ozone* present in a column of Earth's atmosphere. Total ozone includes both *ground-level ozone* and *stratospheric ozone*.

toxaphene: $C_6H_{10}Cl_8$; *toxic organochlorine compound* used as an insecticide (Lapedes 1978).

toxic: Pertains to any substance if it is entering or may enter the *environment* in a quantity or concentration or under conditions having or that may have an immediate or long-term effect on the environment (including living organisms within it) or constituting or that may constitute a danger to human life or health (adapted from Government of Canada 1988).

toxicity: The inherent potential or capacity of a material to cause adverse effects in a living organism (Wells and Rolston 1991).

traditional ecological knowledge (TEK): The knowledge base acquired by Indigenous and local peoples over many hundreds of years through direct contact with the *environment*. This knowledge includes an intimate and detailed knowledge of plants, animals, and natural phenomena, the development and use of appropriate technologies for hunting, fishing, trapping, agriculture, and forestry, and a holistic knowledge or "world view" that parallels the scientific discipline of ecology (Centre for Traditional Knowledge, personal communication). See also *Indigenous ecological and environmental knowledge*.

tree canopy: See *canopy (tree)*.

tree farm licence: A specific tenure arrangement found only in British Columbia that grants exclusive timber harvesting rights and management responsibilities within the area licensed (Natural Resources Canada 1994).

tree-length harvesting: A method of harvesting that includes felling a tree, cutting off its top, and delimbing it before transporting the tree to a mill (Natural Resources Canada 1994).

trend: A persistent tendency in the slope of a *time series* (Environment Canada 1995).

trophic: Relating to processes of energy and *nutrient* transfer from one or more organisms to others in an *ecosystem* (Wells and Rolston 1991). See also *eutrophic*, *trophic level*, and *trophic status*.

trophic level: Functional classification of organisms in a community according to feeding relationships; the first trophic level includes green plants, the second level includes herbivores, and so on (Upper Great Lakes Connecting Channels Study, Management Committee 1988). See also *eutrophic*, *trophic*, and *trophic status*.

trophic status: A measure of the biological productivity in a body of water. *Aquatic ecosystems* are characterized as **oligotrophic** (low productivity), **mesotrophic** (medium productivity), or ***eutrophic*** (high productivity) (Environment Canada et al. 1988). See also *trophic* and *trophic level*.

troposphere: Lowest layer of the atmosphere, extending from ground level to about 11 km above the Earth (Greater Vancouver Regional District 1994). Contains about 95% of the Earth's air and ends at the **tropopause**, the point at which atmospheric temperature starts to increase instead of decrease as one moves farther from the Earth (modified from Arms 1990).

tropospheric ozone: See *ground-level ozone*.

TSS (total suspended solids): The total amount of fibres or particles found in *effluent* (Forestry Canada 1993).

turbid: Refers to water that is cloudy or murky as a result of suspended sediment. Water may become turbid as a result of *soil erosion*, from injections of *effluents* containing particulate matter, or through the churning up of bottom sediments (e.g., via boat traffic in a body of water or by dredging activities).

turbidity: The state of being *turbid*.

U

ultraviolet light: See *ultraviolet radiation*.

ultraviolet radiation: Electromagnetic radiation in the wavelength range 4–400 nm; this range begins at the short-wavelength limit of visible light and overlaps the wavelengths of long x-rays (some scientists place the lower limit at higher levels — up to 40 nm) (Lapedes 1978). Also known as **ultraviolet light**.

urban: An "urban place" or "urban area," as defined by Statistics Canada, has a population of at least 1 000 concentrated within a continuously built-up area, at a density of at least 400 per square kilometre. In this report, "city" means a large urban place with a population of 100 000 or more, and "town" means any smaller urban place.

utilitarian: A term applied to any activity that produces a product useful to humans, typically in some economic sense (Meffe et al. 1994). Also used to describe a system of values that is measured by its contribution to human well-being, usually in terms of health and economic standard of living.

V

VOC (VOCs): See *volatile organic compound*.

volatile organic compound (VOC): Any *organic gas*, such as propane and benzene, and also found in the vapours of substances such as gasoline, numerous solvents, and oil-based paints (Greater Vancouver Regional District 1994). Volatile organic compounds participate in atmospheric photochemical reactions.

vulnerable: In this report, this term refers to an official designation assigned by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The term describes any indigenous *species*, subspecies, or geographically separate *population* that is particularly at risk because of low or declining numbers, small range, or some other reason but is not a *threatened* species. See also *endangered*, *extinct*, *extirpated*, and threatened.

W

waste: Any output from the product or service system that is disposed of (International Organization for Standardization 1995).

waste rock: Valueless rock (unmineralized or weakly mineralized) that must be fractured and removed to gain access to or upgrade ore (Lapedes 1978). It may contain low concentrations of metals or sulphides and is often stored in waste dumps on site.

water erosion: See *soil erosion*.

watershed: An area of land that drains naturally into a stream or other waterway (Natural Resources Canada 1994).

wet deposition: A process of precipitation whereby acidic chemicals, including dilute sulphuric and nitric acids and sulphates, are deposited in rain, snow, etc. See also *acidic deposition*.

wetland: Land that has the water table at, near, or above the land surface or that is saturated for a long enough time to promote wetland or *aquatic* processes and various kinds of biological activity that are adapted to the wet *environment* (National Wetlands Working Group [Canada Committee on Ecological Land Classification] 1988). Includes fen, bog, swamp, marsh, and shallow open water.

wildlife: Pertains to all nondomesticated living organisms, as defined in the Wildlife Policy for Canada (Wildlife Ministers' Council of Canada 1990). It includes not only vertebrate animals (mammals, birds, fish, amphibians, and reptiles) but also invertebrate animals, vascular plants, algae, fungi, bacteria, and all other wild living organisms.

wind erosion: See *soil erosion*.

Z

zooplankton: Microscopic animals that move passively in *aquatic ecosystems* (Lapedes 1978). See also *phytoplankton* and *plankton*.

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Units of Measure

Quantity	Symbol	Unit name
Area	ha	hectare
	km^2	square kilometre
Concentration	ppm	part per million
	ppmv	part per million by volume
	ppmdv	part per million dry volume
	ppb	part per billion
	ppbv	part per billion by volume
	ppt	part per trillion
	pptv	part per trillion by volume
	ng/m^3	nanogram per cubic metre
	$\mu g/m^3$	microgram per cubic metre
	mg/m^3	milligram per cubic metre
	µg/dL	microgram per decilitre
	mg/L	milligram per litre
	ng/g	nanogram per gram
	µg/g	microgram per gram
	mg/kg	milligram per kilogram
	µeq/L	microequivalent per litre
	DU	Dobson unit; 100 DU equals an imaginary layer of pure ozone gas 1 mm thick at standard sea level temperature and pressure

Equivalents: a) Liquids: 1 mg/L = 1 ppm; 1 µg/L = 1 ppb
b) Solids: 1 mg/kg = 1 ppm; 1 µg/kg = 1 ppb; 1 ng/kg = 1 ppt

Quantity	Symbol	Unit name
Energy	Btu	British thermal unit
	MJ	megajoule
	GJ	gigajoule
	PJ	petajoule
	EJ	exajoule
	MW	megawatt
	kWh	kilowatt-hour
	TWh	terawatt-hour
	kV	kilovolt
	$W\ m^{-2}$	watt per square metre
Flow	m^3/s	cubic metre per second
	kg/d	kilogram per day
	t/d	tonne per day
Length	nm	nanometre
	µm	micrometre
	mm	millimetre
	cm	centimetre
	m	metre
	km	kilometre
Pressure	kPa	kilopascal
Radiation	Bq	becquerel
	Bq/m^2	becquerel per square metre
	Bq/kg	becquerel per kilogram
	mSv	millisievert
Time	s	second
	h	hour
	d	day
	yr	year
Volume	mL	millilitre
	L	litre
	dam^3	cubic decametre
	m^3	cubic metre
Weight	ng	nanogram
	µg	microgram
	mg	milligram
	g	gram
	kg	kilogram
	t	tonne
	kt	kilotonne
	Mt	megatonne

SI Prefix	Symbol	Multiplying factor
exa	E	10^{18} (1 000 000 000 000 000 000)
peta	P	10^{15} (1 000 000 000 000 000)
tera	T	10^{12} (1 000 000 000 000)
giga	G	10^{9} (1 000 000 000)
mega	M	10^{6} (1 000 000)
kilo	k	10^{3} (1 000)
hecto	h	10^{2} (100)
deca	da	10^{1} (10)
deci	d	10^{-1} (0.1)
centi	c	10^{-2} (0.01)
milli	m	10^{-3} (0.001)
micro	µ	10^{-6} (0.000 001)
nano	n	10^{-9} (0.000 000 001)
pico	p	10^{-12} (0.000 000 000 001)
femto	f	10^{-15} (0.000 000 000 000 001)

Endnotes

Labour Force Statistics

The industry categories used to present labour force statistics in the relevant part of the first figure in each of Chapters 3–9 have been specially defined to show the relative importance of primary industries and related secondary industries in regional economies. The 1970 Standard Industrial Classification (SIC) has been used as a basis for this retabulation. For the purposes of this report, the primary industry categories (mining, forestry, fisheries, and agriculture) also include the labour force associated with the first stage of processing from the related secondary SIC categories. For example, the *Forestry* category includes SIC 31 — Logging and SIC 39 — Forestry services. It also includes, from the manufacturing category, SIC 251 — Sawmills, planing mills, and shingle mills, SIC 252 — Veneer and plywood mills, SIC 271 — Pulp and paper mills, and SIC 273 — Paper box and bag manufacturers. The *Other manufacturing* category therefore excludes these.

Population Statistics

The following information relates especially to the interpretation of population statistics provided in the first figure in each of Chapters 3–9.

Differences in the geographic unit of measure (e.g., city, Census Metropolitan Area [CMA], Census Agglomeration [CA], etc.) for different population centres make it difficult to compare one urban area with another. Even for the same urban area, changes in the definition of the units over the 1971–1991 period can complicate comparisons.

For urban areas that were defined as CMAs in both 1971 and 1991, the population statistics presented are those of the CMA populations from Census reports of the period. The geographic area covered by some CMAs may have changed because of changes in the boundaries of the municipalities that are included. Some of the population centres may also be affected by a change between 1971 and 1991 in the criteria used to determine whether a municipality is included or not included in a CMA.

For urban areas that were defined as CAs in both 1971 and 1991, the CA populations from the corresponding census reports are presented. For urban areas that were CAs in 1991 but not in 1971, the 1971 figures presented are for the main municipal entity, usually a town or city.

For other population centres, the figures are presented for the administrative unit of the day (city, town, or village). Note that boundaries of individual municipalities may have changed over the period of record.

All data are drawn from the Census of Population and tabulated by Statistics Canada.

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